THE PREDICTORS OF A PROPOSED COMBAT READINESS TEST

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Combat readiness is defined as the ability to accomplish missions on the battlefield, and physical fitness is one of the key elements for combat readiness. The U.S. Army recently proposed a new physical fitness test called the Army Combat Readiness Test (ACRT) to replace the three-decade-old Army Physical Fitness Test (APFT). Determining which physical fitness components are essential to performing well in the proposed ACRT can help U.S. Army Soldiers to attain the physical fitness required for carrying out their duties. Currently, there are no studies that have examined the relationship between the proposed ACRT performance and the components of physical fitness. Therefore, the purpose of this study is to identify the underlying and modifiable components of physical fitness for the proposed ACRT performance.

Forty-three healthy and physically active male subjects (age: 21.5 ± 2.9 yrs; height: 177.9 ± 7.7 cm; mass: 77.8 ± 11.1 kg) participated in one field test session and one laboratory test session. Subjects were assessed with the proposed ACRT in the field test session and physical fitness measurements in the laboratory test session, which included muscular strength and endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility. Backward stepwise linear regression analysis was performed to establish a multiple linear regression model to predict time to completion of the proposed ACRT using the physical fitness measurements.

Muscular endurance, aerobic capacity, body composition, fat-free mass, and agility contributed to a model that predict time to completion of the proposed ACRT ($R^2 = 0.52$, $p < 0.001$). The results indicate that the proposed ACRT assess a combination of physical fitness components, which can be utilized to design a targeted physical fitness training program to enhance combat readiness. Future studies should include greater age range for subjects, female gender, and additional physical fitness components.

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PREFACE

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1.0 INTRODUCTION

Physical fitness contributes significantly to Soldiers' combat readiness.[1] In order to evaluate and track Soldiers' physical fitness, the U.S. Army has utilized the Army Physical Fitness Test (APFT) for almost three decades.[2] The APFT has been criticized for not measuring the physical fitness required for tactical operations,[3-7] so the U.S. Army recently proposed a new physical fitness test called the Army Combat Readiness Test (ACRT).[8-10] The proposed ACRT is designed to measure the physical fitness components required for the Soldiers to perform well during tactical operations.[8-10] Specifically, the designers of the proposed ACRT intended for it to assess the Soldiers' muscular strength, muscular endurance, postural stability, aerobic capacity, anaerobic capacity, agility, flexibility, fat-free mass, and body composition. Among these physical fitness components, determining which components are essential to performing well in the proposed ACRT can help U.S. Army Soldiers to attain the physical fitness required for carrying out their duties. Currently, there are no studies that have examined the relationship between the proposed ACRT performance and the components of physical fitness. Therefore, the purpose of this study is to identify the underlying and modifiable components of physical fitness for the proposed ACRT performance.

1.1 DEFINITION OF COMBAT READINESS

Combat readiness of a Soldier is defined as being capable of carrying out his or her mission successfully.[11] In order to achieve this goal, the U.S. Army aims to provide Soldiers with adequate training to attain combat and technical skills as well as mental and physical fitness.[11] In today's dynamic and volatile operational environments, the need for Soldiers to be trained and prepared in all aspects cannot be stressed enough.[11]

The U.S. Army conducts training based on tasks essential to mission success.[12] Each Soldier needs to be capable of accomplishing tasks specific to his or her military occupational specialty, as well as the common Soldier tasks.[12, 13] The common Soldier tasks are those in which every Soldier must be proficient regardless of age, gender, rank, or branch in order to survive on the battlefield.[12, 13] The common Soldier tasks can be categorized into five categories: *Shoot*, *Move*, *Communicate*, *Survive*, and *Adapt*.[13] The *Shoot* category requires Soldiers to be capable of utilizing rifles and grenades to engage targets effectively. The *Move* category requires Soldiers to be capable of making tactical movements, negotiating obstacles, taking appropriate action in response to enemy fire, and navigating using maps, compass and GPS. The *Communicate* category requires Soldiers to be capable of using visual signals and radios to communicate accurately. The *Survive* category requires Soldiers to be capable of dealing with a chemical or biological attack, evaluating, providing first aid to, and evacuating a casualty, performing counter-improvised explosive device procedures, gathering and reporting intelligence, and performing combatives. Finally, the *Adapt* category requires Soldiers to be capable of dealing with civilians and media with professionalism, improving his or her knowledge and character, and developing physical, emotional, social, spiritual, and family fitness.

Most of the common Soldier tasks previously listed require a high level of physical fitness.[14] Throwing grenades, performing tactical movements, negotiating obstacles, taking cover from enemy fire, evacuating a casualty, and performing combatives are all physically demanding tasks.[14] The U.S. Army strives to train as they fight, so they attempt to develop their Soldiers' physical fitness through a realistic task and performance-oriented physical training program.[14]

1.2 PHYSICAL TRAINING FOR COMBAT READINESS

Combat readiness is heavily influenced by the physical fitness of the Soldier. To perform effectively on the battlefield, the Soldiers must be fit technically, mentally, emotionally, and physically. Deficiency in any of these four aspects will be detrimental to the Soldiers' combat readiness.[1] During the opening phase of the Korean War in 1950, Task Force Smith, a physically and materially unprepared U.S. Army unit was driven off its position while suffering heavy losses by better-prepared North Korean forces.[15] During their retreat, the U.S. Soldiers from this unit had to abandon most of their equipment because they were not physically conditioned to carry it.[15] In contrast, the better-conditioned U.S. Soldiers from the 10th Mountain Division were able to complete their mission in a harsher environment in Somalia in 1993.[4] These U.S. Soldiers were wearing body armor in addition to the gear carried by their 1950 counterpart, while operating in 90 to 100-degree temperatures and 80 to 100-percent humidity.[4]

The U.S. Army physical training program is designed to develop Soldiers' abilities to meet the physical demands of military operations. The recent U.S. Army physical fitness training manual FM 7-22 has outlined the physical requirements needed for performing battlefield tasks, such as run under load, crawl, jump, push, and pull.[14] The U.S. Army then outlined the physical fitness components matching those physical requirements, and designed physical training exercises to develop those physical fitness components.[14]

Injury prevention is another aspect of combat readiness that is related to physical training, but often overlooked in the physical training program. Musculoskeletal injury is a common and significant health problem for military personnel.[16-18] For example, sprains and strains accounted for 49 percent of outpatient visits and were the leading injury type in U.S. military populations in the period 2000–2006.[16] Physical training and sports were one of the top five leading causes of these musculoskeletal injuries, and often resulted in limited duty and lost work time.[17] In addition, many Soldiers' careers were affected by disability due to musculoskeletal injuries, which accounted for 72 percent of all types of disability.[18]

Excessive physical training can also result in musculoskeletal injuries, which undermines combat readiness.[19, 20] For example, high running mileage and an extreme amount of weekly exercise can lead to a variety of musculoskeletal injuries in the military population.[19, 20] On the other hand, insufficient physical training, which leads to low physical fitness, can also contribute to musculoskeletal injuries. Studies demonstrated that Soldiers who can do fewer push-ups and sit-ups, and those who have slower run times, lower peak VO_2, and less flexibility are more likely to suffer from musculoskeletal injuries.[21-23]

1.3 THE DEVELOPMENT OF THE U.S. ARMY PHYSICAL FITNESS TESTS

The U.S. Army has recognized the importance of physical fitness, and published their first official physical fitness test in 1946.[24] The test included five events: *Untimed Pull-Ups*, *Squat Jumps*, *Push-Ups*, *2-Minute Straight-Leg Sit-Ups*, and *300-Yard Outdoor or 250-Yard Indoor*

Shuttle Run. In 1957, a two-test system was adopted by the U.S. Army for physical fitness assessment.[15] One test was for general physical fitness, which was the same as that used in 1946, and another one tested the ability to carry out combat tasks such as *Rush*, *Rope Climb*, and *Man-Carry*. In 1969 and 1973, the two-test system was further refined with respect to its contents, and adapted for different personnel, such as combat service support Soldiers and trainees.[1] The U.S. Army physical fitness assessment was simplified into a single three-event test in 1980, consisting of *2-Minute Push-ups*, *2-Minute Sit-Ups*, and *2-Mile Run*.[2] The three-event test, the Army Physical Fitness Test (APFT), has been utilized by commanders as part of the assessment of their unit's combat readiness.[25] Many unit commanders went as far as using high APFT scores as the only goal for their unit physical training programs,[4] even though it is emphasized in Field Manual (FM) 21-20, *Physical Fitness Training*, that the capabilities for carrying out mission-essential tasks should drive the unit physical training programs, not high APFT scores.

The latest APFT has been utilized across the U.S. Army for almost three decades. Recent studies and observations suggested that the current APFT may be inadequate in providing unit commanders an assessment of their unit's combat readiness.[3-7] This is not surprising, as it is stated in FM 21-20 that APFT is designed to measure muscular endurance and cardiorespiratory fitness, not mission-essential task performance.[25] Due to the criticism of the APFT, the U.S. Army has proposed that the two-test system for physical fitness assessment with the Army Physical Readiness Test (APRT) and the Army Combat Readiness Test (ACRT).[8-10] The APRT is designed to provide a balanced assessment of physical fitness encompassing strength, endurance, and mobility.[10] The proposed ACRT represents the common Warrior Tasks and Battle Drills performed by Soldiers.[8-10] The goal of the proposed ACRT is to measure the physical fitness required for Soldiers to carry out the Warrior Tasks and Battle Drills. Soldiers will complete the following nine events performed in continuous and sequential order: 1) *400-Meter Run*, 2) *Low Hurdles*, 3) *High Crawl*, 4) *Under and Over*, 5) *Casualty Drag*, 6) *Balance Beam Ammo Can Carry*, 7) *Point-Aim-Move*, 8) *100-Yard Shuttle Sprint with Ammo Can*, and 9) *Agility Sprint*. In addition, Soldiers will be asked to complete the events as quickly as possible while wearing the Army Combat Uniform, Advanced Combat Helmet, and combat boots, as well as carrying a dummy M4 rifle. Soldiers will be scored on the accumulated time for all nine events.

1.4 PREDICTING THE PROPOSED ARMY COMBAT READINESS TEST PERFORMANCE

The proposed ACRT includes many physical fitness components that its designers believe to be important for mission success. These components include muscular strength and endurance, postural stability, aerobic capacity, anaerobic power and capacity, flexibility, coordination, speed, and agility.[8-10] However, the designers of the proposed ACRT did not conduct any studies to verify those physical fitness components. Determining which modifiable physical fitness components are crucial to the proposed ACRT performance can help the U.S. Army achieve physical readiness for military operations. If the U.S. Army Soldiers and their physical trainers can learn which modifiable physical fitness components are essential, they can tailor their physical fitness training to match the demands of military operations.

Numerous researchers have studied the correlations between physical fitness components and military task performance, such as load carriage,[26, 27] lifting capabilities,[6, 27] negotiating obstacle courses,[6, 28, 29] and completion of military training or exercises,[30-33] in order to justify the use of less labor-intensive physical fitness tests. Marching while carrying heavy loads is considered a critical military task. Several studies attempted to determine the combination of anthropometric and physical fitness tests that would predict loaded march performance.[26, 27] These studies showed that different predictive models, with input variables such as body mass and muscular endurance, can be developed for loaded march performance of different loads and distances.[14,15] Lifting capabilities are also essential for many military jobs. Soldiers may need to lift single or multiple heavy objects, carry a heavy item for a distance, or drag an injured Soldier to safety.[6, 27] Predictive models with a combination of anthropometric and physical fitness tests such as lean tissue mass and anaerobic power have been developed for these tasks.[6, 27] Several studies have demonstrated the predictive values of anthropometric measures and physical fitness tests on completion of military training or exercises.[30-33] These studies established correlations between success in military training and several physical characteristics, such as muscular strength and endurance, cardiovascular endurance, flexibility, and anaerobic power.[30-33] Teplitzky[30] also found weak correlation between the U.S. Special Forces candidates' APFT scores and their success in the selection program. Daniels et al.[33] reported similar findings in infantry Soldiers in a five-day military field exercise.

Obstacle course performance is highly regarded by the military, as Soldiers must be capable of moving quickly on the battlefield, which is important for both individual survival and unit effectiveness.[2] The proposed ACRT is similar to negotiating an obstacle course, as many events in the test require the same physical abilities, such as *Low Hurdles* and *Balance Beam Ammo Can Carry*. Several studies have attempted to determine the combination of anthropometric and physical fitness tests that predict obstacle course performance.[6, 28, 29] These studies utilized obstacle courses of varying length from seven to nineteen stations, and all showed muscular endurance and anaerobic power as predicting factors for obstacle course performance. Jette et al.[29] found that aerobic capacity was selected in his predictive model in addition to muscular endurance and anaerobic power. The designers of the proposed ACRT also believe that other physical fitness components such as muscular strength, postural stability, anaerobic capacity, coordination, speed, and agility are also important for performance.[8-10] Also, a complete athletic performance assessment usually includes flexibility and body composition.[34] Fat-free mass may also play a significant role in the proposed ACRT performance.[27, 35, 36] Consideration of safety, feasibility, and the power of the prediction model further refine the variables selected for multiple regression analysis, which include muscular strength and endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility.

1.5 DEFINITION OF THE PROBLEM

The intent of the proposed ACRT is to assess the physical readiness of a Soldier to complete common tasks required for military operations.[8-10] Researchers have attempted to predict or find correlating factors between military tasks such as load carriage performance,[26, 27] lifting capabilities,[6, 27] obstacle courses performance,[6, 28, 29] and completion of military training or exercises[30-33] using laboratory-based measures or field-expedient physical fitness tests. Currently, there are no studies that have examined the relationship between the proposed ACRT performance and modifiable physical fitness components.

1.6 PURPOSE

The proposed ACRT is designed to assess a Soldier's ability to carry out common military tasks. Determining which modifiable physical fitness components are essential to good performance in the proposed ACRT can help the U.S. Army achieve physical readiness for military operations. The purpose of this study is to identify the underlying and modifiable components of physical fitness for the proposed ACRT performance.

1.7 SPECIFIC AIMS AND HYPOTHESES

Specific Aim: To establish a multiple linear regression model to predict time to completion of the proposed ACRT in male subjects, using common laboratory measurements of the components of physical fitness (muscular strength, muscular endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility). Specifically, the following variables will be measured: 1) muscular strength: average peak torque performed by dominant knee extension normalized by body mass during an isokinetic knee extension/flexion strength assessment, 2) muscular endurance: total work performed by dominant shoulder external rotation normalized by body mass during an isokinetic shoulder internal/external rotation strength assessment, 3) postural stability: dynamic postural stability index during a two-legged jump and one-legged landing task, 4) aerobic capacity: maximum oxygen uptake (VO_2max) normalized by body mass during a graded treadmill running assessment, 5) anaerobic capacity: average peak power normalized by body mass during a 30-second Wingate protocol, 6) flexibility: sit-and-reach distance during a sit-and-reach assessment,

7) body composition: percent body fat during a BOD POD assessment, 8) fat-free mass: the mass of fat-free tissues calculated using percent body fat, and 9) agility: the fastest time to completion of two Pro Agility tests.

Hypothesis: A strong and significant multiple linear regression model will be built for predicting time to completion of the proposed ACRT in male subjects, using all independent variables: 1) muscular strength: average peak torque performed by dominant knee extension normalized by body mass during an isokinetic knee extension/flexion strength assessment, 2) muscular endurance: total work performed by dominant shoulder external rotation normalized by body mass during an isokinetic shoulder internal/external rotation strength assessment, 3) postural stability: dynamic postural stability index during a two-legged jump and one-legged landing task, 4) aerobic capacity: maximum oxygen uptake (VO_2max) normalized by body mass during a graded treadmill running assessment, 5) anaerobic capacity: average peak power normalized by body mass during a 30-second Wingate protocol, 6) flexibility: sit-and-reach distance during a sit-and-reach assessment, 7) body composition: percent body fat during a BOD POD assessment, 8) fat-free mass: the mass of fat-free tissues calculated using percent body fat, and 9) agility: the fastest time to completion of two Pro Agility tests. A strong prediction model is defined as the ability to account for 40% or more of the variance in the time to completion of the proposed ACRT by male infantry Soldiers. It is hypothesized that each independent variable will contribute equally to prediction of the time needed to complete the proposed ACRT.

1.8 STUDY SIGNIFICANCE

The proposed ACRT represents the common Warrior Tasks and Battle Drills performed by Soldiers, and thus is an attempt to assess the physical readiness of a Soldier to complete common tasks necessary for military operations.[8-10] By identifying the underlying and modifiable physical fitness components for the proposed ACRT performance, U.S. Army Soldiers and their physical trainers can target interventions for those physical fitness components that enhance their combat readiness. Unit commanders may be able to redesign their unit's physical training programs, allocating more time and effort in targeting the physical fitness components that predict the proposed ACRT. In turn, their Soldiers can excel on the battlefield. In addition, by testing those physical fitness components, the U.S. Army may be able to determine if a Soldier should be assigned for combat arms, combat support, or combat service support units, assuming that there are differences in the proposed ACRT performance between these units.

2.0 REVIEW OF LITERATURE

The review of literature will begin with the description of the current U.S. Army's training paradigm in becoming a modular and efficient force capable of conducting simultaneous offensive, defensive, and stability or civil support operations worldwide, as well as how it affects U.S. Army's physical readiness training program. Next, an overview of the history of the U.S. Army physical fitness tests will be presented, and the support and criticism of the current test will be discussed. As the U.S. Army subject experts proposed a new physical fitness test called the Army Combat Readiness Test (ACRT) to assess Soldiers' capability to perform military tasks, previous work on predicting military task performance will be discussed, and the physical fitness components of the proposed ACRT will be analyzed. Finally, the methodology of this study will be discussed based on the literature review.

2.1 THE U.S. ARMY TRAINING METHODOLOGY FOR COMBAT READINESS

The nature of armed conflict has changed greatly in recent decades. The U.S. military has become entangled in more unconventional warfare, and the prospect of conventional warfare is becoming less and less likely since the collapse of the Soviet Union.[11] Recognizing this change, the U.S. Army has been updating its training methodology to develop a modular force capable of conducting full-spectrum operations. The current and future U.S. Army can conduct simultaneous offensive, defensive, and stability or civil support operations worldwide.[11]

2.1.1 Current and Future Operating Environments

Prior to 2001, the U.S. Army assumed that a military force trained for offensive and defensive operations could easily conduct stability or civil operations as well. This concept was proven wrong during the Global War on Terror.[11] The U.S. Army learned that the goals of operations might not be achieved by simply defeating enemy combatants. It is quite possible that the U.S. Army will be called upon to stabilize a region and win the hearts and minds of its local populations quickly after the fighting has ended.[11]

The U.S. Army predicted that the future Army must be able to conduct simultaneous offensive, defensive, and stability or civil support operations.[11] They cannot prepare to simply defeat the enemy combatants, but they must also learn to work with the local population to achieve stability and meet U.S. national objectives. In order to achieve this goal, Soldiers must conduct realistic and task-specific preparatory training. Unit commanders must adapt their training schedules to focus on likely operational environments, whether they are offensive, defensive, stability or civil support operations, or combinations of these.[11]

2.1.2 The U. S. Army's Training Principles

Current and future warfare requires the U.S. Army to be flexible and effective in its training.[11] A unit cannot expect to train on all possible tasks in the allotted time, so they must select training tasks based on unit's proficiency in each task and the needs of the upcoming operations, while weighing the risks of spending less time on certain other tasks.[11] Such an approach requires the combined effort of unit commanders and their subordinate officers and noncommissioned officers. Unit commanders provide training focus, direction, and resources. Subordinate officers and noncommissioned officers execute training and provide feedback.[11]

In order to achieve effectiveness, training is standard-based, performance-oriented, and mission-focused.[11] A standard is the minimum proficiency required to accomplish a task under a set of conditions.[11] U.S. Army-wide standards are usually published in field and technical manuals. However, unit commanders can also establish higher standards for current tasks or standards for tasks yet to be defined by the Army for their own units.[11] The goal of training is to achieve mastery, not just proficiency. Leaders should vary the conditions to make achieving the standard more difficult.[11]

There are three training domains that Soldiers can tap into: institutional, operational, and self-development.[11] Soldier training begins in institutions such as schools and training centers. Soldiers learn individual tasks that will support their future units' main missions, and they are also exposed to tasks performed by other units. When they master the basic skills, they are assigned to their units, and begin operational training. Soldiers build upon their basic skills during operational training, and work toward becoming integral parts of a team. They also gain additional experiences from attending major training events, exercises, and deployment. Self-development supplements the institutional and operational domains. It helps Soldiers to enhance their skills and knowledge of their current positions, as well as prepare for future ones. Self-development can be achieved through many sources, including reading, taking courses, and pursuing academic degrees.

2.1.3 The U.S. Army's Training Management

In order to conduct flexible and effective training for current and future warfare, the U.S. Army requires good training management. Training management is a process that helps unit commanders to plan, prepare, execute, and assess training.[11] Training management also helps units achieve readiness through a three-phase cycle: *Reset*, *Train/Ready*, and *Available*.[11] Units enter the *Reset* phase when they return from deployment or complete their planned deployment window. Units enter the *Train/Ready* phase when they begin conducting intensive training to prepare for deployment. Units enter the *Available* phase when they deploy to a current operation or are available for immediate deployment. Afterward, they return to the *Reset* phase, and the cycle begins again.

Unit commanders formulate training plans based on their units' mission-essential tasks and pre-training assessment.[11] Units' mission-essential tasks consist of general tasks, core tasks, and directed mission tasks.[11] General tasks are tasks that all types of units must be able to perform, while core tasks are specific to units. Directed mission tasks are tasks that units must perform to accomplish the upcoming operations. Unit commanders perform pre-training assessment to prioritize training tasks and develop training strategy.[11] They will then schedule training events, allocate resources, and coordinate training site support. Afterward, they will brief their higher commanders to obtain approval for their plans.[11]

Unit commanders prepare for training events by selecting and preparing trainers, verifying the time, resources, and site support, and performing rehearsals.[11] Trainers are critical to the success of training events.[11] Unit commanders must make sure that trainers are competent and understand how the training relates to the units' readiness. Training is executed using *Crawl-Walk-Run* approach.[11] That is, Soldiers begin with very basic conditions (*Crawl*), take on more difficult conditions (*Walk*), and then attempt to complete the task under realistic conditions similar to those of combat (*Run*). After each training event, unit commanders judge their unit's ability to perform their mission-essential tasks and achieve their missions during deployment.[11] Assessment is based on unit commanders' personal observations, reports, and after-action reviews.[11] The ratings from the assessment help individual unit commanders determine the next course of action for their unit's training.[11]

2.2 THE U.S. ARMY PHYSICAL READINESS TRAINING PROGRAM

The U.S. Army Physical Readiness Training Program follows the overall training principles for conducting full-spectrum operations. It is designed to assist Soldiers in performing mission-essential tasks. Successful completion of missions, and even Soldiers' lives depend on their physical readiness.[14]

2.2.1 The U.S. Army's Physical Readiness Training Principles

As overall U.S. Army training principles, the U.S. Army Physical Readiness Training Program requires flexibility and effectiveness.[14] Flexibility comes from cooperation and communication between unit commanders and their subordinate officers and noncommissioned officers. Unit commanders provide guidance and resources based on the mission given to the units, while their subordinate officers and noncommissioned officers execute training and identify the units' needs.[14] The U.S. Army Physical Readiness Training Program is designed to align with units' mission-essential tasks.[14] Table 1 demonstrates the physical requirements of several mission-essential tasks. Physical requirements of mission-essential tasks are further condensed into physical fitness components (Table 2). Based on the physical fitness components required by mission essential tasks, the U.S. Army has developed a number of physical readiness training activities to help Soldiers perform those tasks.

Table 1. Physical Requirements of Mission-Essential Tasks

Shoot	Physical Requirements
Employ hand grenades	Run under load, jump, bound, high/low crawl, climb, push, pull, squat, lunge, roll, stop, start, change direction, get up/down, and throw.
Move	**Physical Requirements**
Perform individual movement techniques	March/run under load, jump, bound, high/low crawl, climb, push, pull, squat, lunge, roll, stop, start, change direction, and get up/down.
Navigate from one point to another	March/run under load, jump, bound, high/low crawl, climb, push, pull, squat, lunge, roll, stop, start, change direction, and get up/down.
Move under fire	Run fast under load, jump, bound, crawl, push, pull, squat, roll, stop, start, change direction, and get up/down.
Survive	**Physical Requirements**
Perform combatives	React to man-to-man contact: push, pull, run, roll, throw, land, manipulate body weight, squat, lunge, rotate, bend, block, strike, kick, stop, start, change direction, and get up/down.
Adapt	**Physical Requirements**
Assess and respond to threats (escalation of force)	React to man-to-man contact: push, pull, run, roll, throw, land, manipulate body weight, squat, lunge, rotate, bend, block, strike, kick, stop, start, change direction, and get up/down. Run under load, jump, bound, high/low crawl, climb, push, pull, squat, lunge, roll, stop, start, change direction, get up/down, and throw.
Battle Drills	**Physical Requirements**
React to contact	Run fast under load, jump, bound, crawl, push, pull, squat, roll, stop, start, change direction, and get up/down.
Evacuate a casualty	Squat, lunge, flex/extend/rotate trunk, walk/run, lift, and carry.

Table 2. Physical Fitness Components Required by Mission-Essential Tasks

Physical Fitness Components	Employ hand grenades	Perform individual movement techniques	Navigate from one point to another	Move under fire	Perform combatives	Assess and respond to threats	React to contact	Evacuate a casualty
Strength								
Muscular strength	X	X	X	X	X	X	X	X
Muscular endurance	X	X	X	X	X	X		X
Endurance								
Anaerobic endurance	X	X	X	X	X	X	X	X
Aerobic endurance		X	X			X		X
Mobility								
Agility	X	X	X	X	X	X	X	X
Balance	X	X	X	X	X	X	X	X
Coordination	X	X	X	X	X	X	X	X
Flexibility	X	X	X	X	X	X	X	X
Posture	X	X	X	X	X	X	X	X
Stability	X	X	X	X	X	X	X	X
Speed	X	X	X	X	X	X	X	X
Power	X	X	X	X	X	X	X	X

The U.S. Army Physical Readiness Training Program emphasizes *Precision*, *Progression*, and *Integration*.[14] In terms of *Precision*, Soldiers must perform exercises using the correct form rather than attempt to use compensatory motions to finish the exercise. *Progression* refers to systematic and gradual increases in the intensity or duration of exercises. This allows the body to adapt positively to training without risk of injury. *Integration* refers to proper balance of training in all physical fitness components as well as appropriate recovery from training. Because mission-essential tasks usually involve combinations of strength, endurance, and mobility, physical readiness training activities need to encompass all three physical fitness components as well. Unit commanders also need to consider the physical demand of other unit activities when planning and scheduling physical readiness training, so that their Soldiers have ample time for recovery from exercises. Since physical training is one of the leading causes of musculoskeletal injury in the military population, unit commanders are urged to follow the *Precision*, *Progression*, and *Integration* approach when designing physical readiness training programs.[14]

2.2.2 The U.S. Army Physical Readiness Training Management

Unit commanders employ the same process as described in FM 7-0 to plan, prepare, execute, and assess their units' physical readiness training.[14] Similarly to the U.S. Army's readiness cycle (*Reset*, *Train/Ready*, and *Available*), the U.S. Army Physical Readiness Training program has four phases: *Initial Conditioning*, *Toughening*, *Sustaining*, and *Reconditioning*.[14] The *Initial Conditioning* phase enables potential candidates, such as Reserve Officer Training Corps cadets, to learn and adapt to the U.S. Army Physical Readiness Training Program. Soldiers in the initial phase of military training enter the *Toughening* phase, and perform basic fitness activities to transition to the *Sustaining* phase. Soldiers assigned to their units perform the *Sustaining* phase training to help them meet the physical requirements of their units' mission-essential tasks. Soldiers may need to return to the *Reconditioning* phase of training due to injuries or other reasons, so that they can safely transition back to the *Toughening* and *Sustaining* phases. Operational units may also utilize the three-phase readiness cycle to plan their physical readiness training.

2.3 HISTORY OF U.S. ARMY PHYSICAL FITNESS TEST

The U.S. Army physical fitness tests have been implemented in the U.S. Army to provide Soldiers and unit commanders a tool to assess combat readiness of individuals and units for decades.[1, 2, 15, 24, 37-39] The names of the tests as well as their contents have seen changes over the years (Table 3).

Table 3. Physical Fitness Components of Army Physical Fitness Test (1946 to Present)

	Physical Fitness Components								
	Muscular Strength	Muscular Endurance	Cardiovascular Endurance	Flexibility	Agility & Coordination	Anaerobic Power	Speed	Postural Stability	Anaerobic Capacity
1946 and 1950									
PFT	X	X	X		X				
1957									
PFT	X	X	X		X				
PAT		X	X			X			
1969									
PCPT	X	X	X		X				
AMPFT			X	X					
ATPFT		X	X						
1973									
APFT	X	X	X		X	X			
SSPFT	X	X	X		X	X			
BPFT	X	X	X		X	X			
IWPFT	X	X	X	X	X	X			
MPFT	X	X	X		X	X			
ATPFT		X	X						
RSPFT	X	X	X		X	X			
1980, 1992, and 1998									
APFT		X	X						
RPFT			X						
2011									
APRT	X	X	X		X	X	X		
ACRT	X	X	X		X	X	X	X	X

Note: PFT - Physical Fitness Test; PAT – Physical Achievement Test; PCPT – Physical Combat Proficiency Test; AMPFT – Army Minimum Physical Fitness Test – Male; ATPFT – Airborne Trainee Physical Fitness Test; APFT (1973) – Advanced Physical Fitness Test; SSPFT – Staff and Specialist Physical Fitness Test; BPFT – Basic Physical Fitness Test; IWPFT – Inclement Weather/Limited Facility Physical Fitness Test; MPFT – Minimum Physical Fitness Test; RSPFT – Ranger/Special Forces Physical Fitness Qualification Test; APFT (1980, 1992, and1998) – Army Physical Fitness Test; RPFT – Ranger Physical Fitness Test; APRT – Army Physical Readiness Test; ACRT – Army Combat Readiness Test

In 1946, the first U.S. Army Physical Fitness Test was published as FM 21-20.[24] The test was designed to measure Soldiers' muscular strength, muscular endurance, cardiovascular endurance, agility, and coordination. Soldiers were required to complete five events: *Untimed Pull-Ups*, *Squat Jumps*, *Push-Ups*, *2-Minute Straight-Leg Sit-Ups*, and *300-Yard Outdoor* or *250-Yard Indoor Shuttle Run*. If no space was available for *300-Yard Outdoor* or *250-Yard Indoor Shuttle Run*, *60-Second Squat Thrusts* were to be used (Appendix A). The FM 21-20 published in 1950 kept the same physical fitness test.[37]

In 1957, the new version of FM 21-20 made many changes based on feedback from the Korean War.[15] Soldiers reported that the ill-equipped but well-trained North Korean Army was able to rout the U.S. forces in the opening phase of the war. While retreating, the U.S. Soldiers had to abandon most of their equipment because they were not physically conditioned to carry it.[15] Two tests were recommended in this version of the manual – a physical fitness test to determine Soldiers' general fitness and a physical achievement test to determine solders' ability to carry out combat tasks, with the latter administered to combat arms Soldiers only. The physical fitness test was the same as that of the previous version, consisting of *Untimed Pull-ups*, *Squat Jumps*, *Push-ups*, *2-Minute Straight-Leg Sit-ups*, and *300-Yard Shuttle Run* (Appendix A). The physical achievement test consisted of *75-Yard Dash*, *Triple Jump*, *5-Second Rope Climb*, *150-Yard Man Carry*, and *1-Mile Run* (Appendix A).

The most significant changes to the 1969 version of FM 21-20 were the expansion of physical fitness tests, consisting of the Physical Combat Proficiency Test (PCPT), the Army Minimum Physical Fitness Test – Male (AMPFT), and the Airborne Trainee Physical Fitness Test (ATPFT).[1]

The Physical Combat Proficiency Test (PCPT) was the primary U.S. Army Physical Fitness Test in 1969, and was designed to measure the strength, endurance, agility, and coordination required to perform combat tasks. The PCPT included five events: 1) *40-Yard Low Crawl* for testing crawling ability and endurance, 2) *Horizontal Ladder* for testing coordination, arm and shoulder strength and endurance, 3) *Dodge, Run, and Jump* for testing agility and coordination in making rapid changes of direction while running, as well as jumping ability, 4) *Grenade Throw* for testing strength and coordination required for throwing for distance and accuracy, 5) *1-Mile Run* for testing the cardiovascular and muscular endurance. An alternate event for *Grenade Throw – 150-Yard Man Carry* – was used for Soldiers in basic combat training, advanced individual training, and combat support training (Appendix A).

The Army Minimum Physical Fitness Test – Male (AMPFT) was used when Soldiers could not participate in the Physical Combat Proficiency Test (PCPT) due to duties or lack of facilities. The AMPFT included six primary events and six alternate events: 1) *Squat Bender* or *Squat Stretch* for testing flexibility, 2) *Push-Up* or *Eight Count Push-Up* for testing shoulder strength, 3) *Sit-Up* or *Body Twist* for testing abdominal strength, 4) *Legs Over* or *Leg Spreader* for testing back strength, 5) *Squat Thrust* or *Mountain Climber* for testing leg strength, and 5) *Stationary Run* or *One-Half-Mile Run* for testing cardiovascular endurance (Appendix A).

The Airborne Trainee Physical Fitness Test (ATPFT) was used to determine the physical condition of applicants for acceptance to and retention in the Airborne training course. The ATPFT included five events: 1) *Chin-Up* for testing arm and shoulder flexor strength, 2) *Knee Bender* for testing the strength and endurance of the leg muscles, 3) *Push-Up* for testing arm and shoulder strength, 4) *Sit-Up* for testing abdominal strength, and 5) *1-Mile Run* for testing cardiovascular endurance (Appendix A).

U.S. Army Physical Fitness Tests saw further expansion in the FM 21-20 of 1973.[38] There were seven tests: Advanced Physical Fitness Test, Staff and Specialist Physical Fitness Test, Basic Physical Fitness Test, Inclement Weather/Limited Facility Physical Fitness Test, Minimum Physical Fitness Test, Airborne Trainee Physical Fitness Qualification Test, and Ranger/Special Forces Physical Fitness Qualification Test.

The Advanced Physical Fitness Test was used for Soldiers in combat and combat support units, advanced individual training, and combat support training. The Advanced Physical Fitness Test included five events: 1) *Inverted Crawl* for testing arm and leg coordination as well as overall strength and endurance, 2) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 3) *Horizontal Ladder* for testing coordination, arm and shoulder strength and endurance, 4) *Run, Dodge, and Jump* for testing agility, coordination, and anaerobic power, and 5) *2-Mile Run* for testing cardiovascular and leg muscle endurance (Appendix A).

The Staff and Specialist Physical Fitness Test was used for Soldiers in combat service support and non-deployable units, as well as students, faculty, and staff at service schools. The Staff and Specialist Physical Fitness Test included five events: 1) *Push-Ups* for testing arm and shoulder strength, 2) *Run, Dodge, and Jump* for testing agility, coordination, and anaerobic power, 3) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 4) *Horizontal Ladder* for testing coordination, arm and shoulder strength and endurance, and 5) *1-Mile Run* for testing cardiovascular and leg muscle endurance (Appendix A).

The Basic Physical Fitness Test was used for trainees undergoing Basic Combat Training. The Basic Physical Fitness Test included five events: 1) *Inverted Crawl* for testing arm and leg coordination as well as overall strength and endurance, 2) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 3) *Horizontal Ladder* for testing coordination, arm and shoulder strength and endurance, 4) *Run, Dodge, and Jump* for testing agility, coordination, and anaerobic power, and 5) *1-Mile Run* for testing cardiovascular and leg muscle endurance (Appendix A).

The Inclement Weather/Limited Facility Physical Fitness Test was a substitute test for the Advanced Physical Fitness Test, Staff and Specialist Physical Fitness Test, and Basic Physical Fitness Test when severe weather prevented administration of the aforementioned tests. The Inclement Weather/Limited Facility Test included five events: 1) *Push-Ups* for testing arm and shoulder strength, 2) *Bend and Reach* for testing leg and back muscle endurance and general flexibility, 3) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 4) *Squat Thrust* for testing the coordination and strength and endurance of the leg muscles, and 5) *80-Meter Shuttle Run* for testing anaerobic power, coordination, and agility (Appendix A).

The Minimum Physical Fitness Test was used for Soldiers above age 40 to retirement who volunteered to take the test. The Minimum Physical Fitness Test included five events: 1) *Push-Ups* for testing arm and shoulder strength, 2) *Run, Dodge, and Jump* for testing agility, coordination, and anaerobic power, 3) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 4) *Squat Thrust* for testing the coordination, strength and endurance of the leg muscles, and 5) *0.5-Mile Run* for testing cardiovascular and leg muscle endurance (Appendix A).

The Airborne Trainee Physical Fitness Qualification Test was used for applicants to the Airborne course. The Airborne Trainee Physical Fitness Qualification Test included five events: 1) *Chin-Ups* for testing arm and shoulder strength, 2) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 3) *Push-Ups* for testing arm and shoulder strength, 4) *Knee Bender* for testing the strength and endurance of the leg muscles, and 5) *1-Mile Run* for testing cardiovascular and leg muscle endurance (Appendix A).

The Ranger/Special Forces Physical Fitness Qualification Test was used for applicants of the Ranger and Special Forces Courses. The Ranger/Special Forces Physical Fitness Qualification Test included six events: 1) *Inverted Crawl* for testing arm and leg coordination as well as overall strength and endurance, 2) *Bent-Leg Sit-Ups* for testing the strength of the abdominal muscles, 3) *Push-Ups* for testing arm and shoulder strength, 4) *Run, Dodge, and Jump* for testing agility, coordination, and anaerobic power, 5) *2-Mile Run* for testing cardiovascular and leg muscle endurance, and 6) *Swim Event* for testing the ability to swim 15 meters (m) or 50 meters (m) with gear (Appendix A).

In 1980, the Army Physical Fitness Test (APFT) became the sole assessment tool for U.S. Army Soldiers' physical fitness.[2, 25, 39] The 1980 FM 21-20 stated that the APFT is a three-event physical performance test used to assess muscular endurance and cardiorespiratory fitness, and that it helped to assess a Soldier's ability to undertake fitness-related tasks.[25] The APFT consisted of *2-Minute Push-Ups*, *2-Minute Sit-Ups*, and a *2-Mile Run* (Appendix A). The Airborne and Special Forces Trainee Physical Fitness Qualification also used the APFT.

The Ranger Physical Fitness Test (RPFT) was used to determine the physical condition of applicants for acceptance to and retention in the Ranger Training Course. The RPFT included four events: 1) *Push-Ups* for testing arm and shoulder strength, 2) *Sit-Ups* for testing abdominal strength, 3) *5-Mile Run* for testing cardiovascular endurance, and 4) *Chin-Ups* for testing arm and shoulder flexor strength (Appendix A).

After three decades of continual use of the three-event APFT, the U.S. Army proposed two physical fitness tests to replace the APFT: the Army Physical Readiness Test (APRT) and the Army Combat Readiness Test (ACRT).[8-10] The proposed APRT and the ACRT are designed to reflect Soldiers' ability to perform Warrior Tasks and Battle Drills. The APRT is designed to provide a balanced assessment of physical fitness encompassing strength, endurance, and mobility.[10] Soldiers will complete 5 events: 1) *60-Yard Shuttle Run* for testing lower-body muscular strength, anaerobic power, speed, agility, and coordination, 2) *One-Minute Rower* for testing total body muscular endurance, coordination, and trunk stability, 3) *Standing Long Jump* for testing muscular strength, anaerobic power, and coordination, 4) *One-Minute Push-up* for testing upper-body muscular endurance and trunk stability, and 5) *1.5-Mile Run* for testing-lower body muscular endurance, aerobic capacity, and speed stability (Appendix A).

The proposed ACRT represents the common Warrior Tasks and Battle Drills performed by Soldiers. The goal of the proposed ACRT is to measure the strength, endurance, and mobility required for battle. Soldiers will complete the following nine events performed in continuous and sequential order: 1) *400-Meter Run*, 2) *Low Hurdles*, 3) *High Crawl*, 4) *Under and Over*, 5) *Casualty Drag*, 6) *Balance Beam Ammo Can Carry*, 7) *Point-Aim-Move*, 8) *100-Yard Shuttle Sprint with Ammo Can*, and 9) *Agility Sprint*. In addition, Soldiers will be asked to complete the events as quickly as possible while wearing the Army Combat Uniform, Advanced Combat Helmet, and combat boots, and carrying a dummy M4 rifle.

The APFT has seen continual use for three decades. The reason for its longevity is probably due to its ease of administration, requiring no equipment, and being gender-neutral.[40] While the Physical Combat Proficiency Test required pre-constructed facilities and numerous test scorers, the APFT could be administered almost anywhere and with few scorers.[1, 2] With the integration of women into previously all-male units, the APFT allowed units to use the same test format for both genders, and was believed to be more equitable for women.[40]

Although the APFT has many benefits, it is criticized for not measuring some aspects of physical fitness, such as muscular strength, coordination, agility, anaerobic power, speed and postural stability that may be important in performing Soldiers' duties.[8-10] This is not surprising as it is stated in FM 21-20 that the APFT is designed to measure muscular endurance and cardiorespiratory fitness, not mission-essential task performance.[39] Several studies showed that the APFT did not correlate with military task performances, such as load carriage,[7] casualty rescue,[6] and completion of military field exercises.[33] Even though FM 21-20 explicitly stated that the mission-essential tasks should drive the physical training program design, 85 percent of the unit commanders considered high APFT scores to be the goal of their unit's physical training programs, which is counter to the intent of the FM 21-20.[4] Finally, observations from the recent Global War on Terror suggested that future warfare might be fought as non-linear battles, which require all military personnel, regardless of branch, to have the physical and technical capability for combat.[3] The current APFT does not reflect the tasks Soldiers complete during combat.[3] These criticisms are mostly addressed in the proposed ACRT, as it is closely linked to common Warrior Tasks and Battle Drills performed by the Soldiers.

2.4 PREDICTING MILITARY TASK PERFORMANCE

Developing predictive models for military task performance can provide invaluable information to the military. They would enable military leaders to learn about the preparedness of their troops, as well as help select the suitable personnel suitable for different positions. These models could also help identify the key physical abilities for battlefield performance, and could be utilized to develop and evaluate a battle-focused physical training program.[6] There are four categories of military task performance prediction in the literature: load carriage,[26, 27] lifting capabilities,[6, 27] negotiating obstacle courses,[6, 28, 29] and completion of military training or exercises.[4,5,20,21] Of the four categories, literature on negotiating obstacle courses may provide better insight into developing the predictive model for the proposed ACRT. The proposed ACRT is similar to obstacle courses, because they all require a variety of physical fitness components in order to excel.

2.4.1 Load Carriage Performance

Marching while carrying heavy loads is considered a critical military task. Linear regression models have been developed in several studies to predict load carriage performance from physical fitness test performance and body composition. Williams et al.[26] recruited 148 male and female British Army recruits to participate in a study to determine whether load-carriage performance could be predicted by field tests of strength and endurance, as well as simple anthropometric tests. Subjects were asked to complete a 3.2-km loaded march with a backpack load of 15 kg or 25 kg as fast as possible. Several predictive models (r^2 = 0.40–0.81) were developed which included age, gender, stature, body fat percentage, fat-free mass, body mass, shuttle run time, and static lift strength. Rayson et al.[27] recruited 304 male and 75 female British Army Soldiers to participate in a study to determine which combination of physical fitness tests could predict British Army criterion task performance, such as lifting, carrying, and loaded march. For the loaded march, subjects were instructed to complete a 12.8-km course as fast as possible while carrying a 15-kg, 20-kg, or 25-kg rucksack. Several predictive models (r^2 = 0.40–0.75) were developed that included gender, body mass, body fat percentage, VO_2max, static arm flexion endurance, and Multistage Fitness Test. In summary, load carriage performance can be predicted with anthropometric and physical fitness test performance.

2.4.2 Lifting Capabilities

Lifting capabilities are essential for many military jobs. Rayson et al.[27], in the same study mentioned above, had subjects complete three types of lifting tasks: a single lift task, a continuous carry task, and a repetitive lift and carry task. Several predictive models (r^2 = 0.38–0.88) were developed which included gender, arm span, fat free mass, strength, muscular endurance, and anaerobic power. Harman et al.[6] recruited 32 civilian males to participate in a study to determine whether field-expedient tests could predict simulated battlefield task performance, such as running for cover, negotiating obstacles, and rescuing casualties. For the casualty rescue task, subjects were asked to drag an 80-kg mannequin for 50 m as fast as possible. A predictive model (r^2 = 0.59) was developed which included body mass, vertical jump height, 3.2-km run time, and number of push-ups. Sharp et al.[35] recruited 222 male and female Soldiers to determine whether anthropometric and physical fitness tests can predict a maximal lifting test performance. A predictive model (r^2 = 0.79) was developed which included fat-free mass, upright pull muscular strength, and gender. Teves et al.[36] recruited 1984 male and female trainees to determine whether anthropometric and physical fitness tests could predict another maximal lifting test performance. A predictive model (r^2 = 0.47) was developed which included fat-free mass and incremental lifting performance. In summary, lifting capabilities can be predicted with anthropometric and physical fitness test performance.

2.4.3 Obstacle Course Performance

Soldiers must be capable of moving quickly on the battlefield, as it is important for both individual survivability and unit effectiveness. Harman et al.[6], in the same study mentioned above, had subjects complete a eight-station obstacle course. A predictive model (r^2 = 0.67) was developed that included horizontal jump distance, vertical jump height, and the number of sit-ups. Bishop et al.[28] utilized an 11-station obstacle course. The authors also performed various anthropometric and physical fitness tests, including skin folds, upper- and lower-body aerobic and anaerobic power, muscular strength, and endurance on 47 civilian males, and developed a predictive model (r^2 = 0.42) that included body fat percentage, body mass, arm maximal anaerobic power, and leg mean anaerobic power relative to body mass. Jette et al.[29, 41] utilized a 19-station obstacle course. The authors performed various anthropometric and physical fitness tests, including height, weight, skin folds, chest and waist girths, aerobic capacity, anaerobic power, and muscular strength and endurance on 43 military personnel and civilians, and developed a predictive model (r^2 = 0.81) that included body fat percentage, aerobic and anaerobic power, and sum of muscular strength measurement. In summary, obstacle course performance can be predicted using anthropometric and physical test performance. The difference between predictive models among the studies may be due to the length of the obstacle courses. The length of the obstacle course in the study of Jette et al. study may explain why aerobic capacity was included in their predictive equation, while only anaerobic power or capacity were selected in the studies of Bishop et al. and Hartman et al. The proposed ACRT has only nine stations; hence it is unlikely that aerobic capacity will be a significant factor.

2.4.4 Completion of Military Training or Exercises

Several studies have demonstrated the predictive values of anthropometric measures and physical fitness tests on the completion of military training or exercises. Teplitzky[30] studied 5996 U.S. Special Forces candidates' APFT scores and load carriage performance to predict their success in the selection program. The author found weak correlations between APFT scores and success of the candidates (r = 0.23–0.28), but stronger correlations between the completion time of a load carriage march test and success of the candidates (r = -0.28–-0.40). Hogan et al.[31] analyzed 145 U.S. Navy students' and fleet divers' data on muscular strength, anaerobic power, muscular endurance, cardiovascular endurance, flexibility, postural stability, neuromuscular endurance, and anthropometric measurement to predict their abilities to complete explosive ordnance disposal training. The authors established correlations between training completion and *1.5-Mile Run*, *Pull and Lift Strength*, *Medicine Ball Throw*, *Arm Ergometer*, *Vertical Jump*, *Sit-Ups*, *Dynamic Flexibility*, and *Purdue Pegboard Assembly* with r ranges from -0.20–0.36. Daniels et al.[33] tested 33 infantry Soldiers for their aerobic power, lifting capability, and APFT scores, and followed their performance during a five-day military field exercise. The authors reported no correlations between aerobic power or APFT score and military field exercise performance, but some correlations between lifting capability and military field exercise performance (r = 0.39). In a similar study, Knapik et al.[32] studied 34 infantry Soldiers for their body composition, muscular strength, lifting capability, aerobic power, anaerobic power and capacity, and APFT scores. The authors found no correlations between body composition, aerobic power, or APFT score and military field exercise performance, but some correlations between muscular strength (r = 0.36), lifting capability (r = 0.36), anaerobic power (r = 0.46), and anaerobic capacity (r = 0.43) and military field exercise performance. In summary, the completion of military training or exercises is related to physical fitness test performance.

2.5 PHYSICAL FITNESS COMPONENTS OF THE PROPOSED ARMY COMBAT READINESS TEST

The proposed ACRT is not only designed to provide a more accurate picture of a Soldier's ability to perform battlefield tasks, but also to assess strength, endurance, and mobility correlation with battlefield performance.[10] Soldiers need to perform nine events in continuous and sequential order: 1) *400-Meter Run*, 2) *Low Hurdles*, 3) *High Crawl*, 4) *Under and Over*, 5) *Casualty Drag*, 6) *Balance Beam Ammo Can Carry*, 7) *Point-Aim-Move*, 8) *100-Yard Shuttle Sprint with Ammo Can*, and 9) *Agility Sprint*.[10] Each event requires different physical fitness components. Collectively, they may present the key physical fitness components required to excel at the proposed ACRT.

The U.S. Army has provided the physical fitness components required for each event in the proposed ACRT,[10] but has not shown which muscles and metabolic energy systems are utilized. In order to remedy this knowledge gap and facilitate choosing appropriate test protocols, the principal investigator will perform needs analysis, including muscular involvement and metabolic energy utilization.[34]

2.5.1 *400-Meter Run*

The *400-Meter Run* requires Soldiers to move with their weapon systems. When receiving indirect fire, Soldiers may be required to run longer distances to avoid casualties. The U.S. Army stated that *400-Meter Run* measures total body muscular endurance, anaerobic capacity, coordination, and speed stability.[10] Of these, the physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are total body muscular endurance and anaerobic capacity.

Muscular involvement in the *400-Meter Run* is shown in Table 4 below.[42] The primary muscles for performing this event are the gluteus maximus, vastus lateralis, vastus intermedius, vastus medialis, rectus femoris, biceps femoris, and adductor magnus. Metabolic analysis indicates that the primary energy system utilized during this event is the fast glycolysis system, based on the duration of the event which is 30 seconds to 2 minutes.[34]

Table 4. Muscular Involvement in the *400-Meter Run*

Muscular Involvement in the 400-Meter Run	Primary Movers		Accessory Muscles	
Upper Body			• Trapezius • Anterior deltoid • Medial deltoid • Posterior deltoid • Biceps brachii • Brachioradialis • Triceps brachii	• Flexor digitorum • Flexor carpi radialis • Extensor carpi radialis • Extensor digitorum
Trunk			• Obliquus externus • Transversus abominis • Erector spinae • Quadratus lumborum	
Lower Body	• Gluteus maximus • Vastus lateralis • Vastus intermedius • Vastus medialis • Rectus femoris • Biceps femoris • Adductor magnus		• Iliopsoas • Sartorius • Tensor fasciae latae • Tibialis anterior • Extensor digitorium • Extensor halluces	• Peroneus • Soleus

2.5.2 *Low Hurdles*

While under fire, Soldiers may be required to move over low-lying obstacles to find cover and concealment. For the *Low Hurdle* event, Soldiers will leap over two 0.5-m hurdles, placed on 9.1-m-long course while running as fast as possible. The U.S. Army stated that *Low Hurdles* measures upper- and lower-body muscular endurance, agility, postural stability, coordination, and speed stability.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are upper- and lower-body muscular endurance and postural stability.

Muscular involvement in the *Low Hurdle* is shown in Table 5 below.[42] The primary muscles for performing this event are gluteus maximus, vastus medialis, rectus femoris, sartorius, adductor longus, adductor magnus, semitendinosus, semimembranosus, gracilis, biceps femoris, gastrocnemius, and soleus. Metabolic analysis indicates that the primary energy system utilized during this obstacle is the phosphagen system, based on the duration of the event being less than six seconds.[34]

Table 5. Muscular Involvement in the *Low Hurdles*

Muscular Involvement in the Low Hurdles				
	Primary Movers		Accessory Muscles	
Upper Body			• Trapezius • Anterior deltoid • Medial deltoid • Posterior deltoid • Biceps brachii • Brachioradialis • Triceps brachii • Flexor digitorum	• Flexor carpi radialis • Extensor carpi radialis • Extensor digitorum
Trunk			• Obliquus externus • Obliquus internus • Rectus abdominis • Transversus abominis	• Erector spinae • Quadratus lumborum
Lower Body	• Gluteus maximus • Vastus medialis • Rectus femoris • Sartorius • Adductor longus • Adductor magnus	• Semitendi-nosus • Semimembra-nosus • Gracilis • Biceps femoris • Gastrocnemius • Soleus	• Pectineus • Piriformis • Gluteus medius • Tibialis anterior • Tibialis posterior	

2.5.3 *High Crawl*

While under fire, Soldiers may be required to high crawl to find cover and concealment. During the *High Crawl* event, Soldiers will maintain four points of contact while high-crawling through a 9.1-m course as fast as possible. The U.S. Army stated that *High Crawl* measures upper- and lower-body muscular endurance, agility, postural stability, coordination, and speed stability.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are upper- and lower-body muscular endurance and postural stability.

Muscular involvement in the *High Crawl* is shown in Table 6 below.[42] The primary muscles for performing this event are the trapezius, posterior deltoid, rhomboid, infraspinatus, teres major, latissimus dorsi, biceps brachii, brachialis, brachioradialis, obliquus externus, quadratus lumborum, tensor fasciae latae, gluteus medius, gluteus minimus, piriformis, gluteus maximus, superior gemellus, obturator externus, vastus intermedius, rectus femoris, and vastus lateralis. Metabolic analysis indicates that the primary energy systems utilized are the phosphagen and fast glycolysis system, based on the duration of the event being six to 30 seconds.[34]

Table 6. Muscular Involvement in the *High Crawl*

Muscular Involvement in the High Crawl	Primary Movers		Accessory Muscles	
Upper Body	• Trapezius • Posterior deltoid • Rhomboid • Infraspinatus • Teres major • Latissimus dorsi • Biceps brachii	• Brachialis • Brachioradialis	• Levator scapulae • Anterior deltoid • Medial deltoid • Teres minor • Flexor carpi radialis • Flexor digitorum	• Extensor carpi radialis
Trunk	• Obliquus externus • Quadratus lumborum		• Transverse abdominis • Erector spinae	
Lower Body	• Tensor fasciae latae • Gluteus medius • Gluteus minimus • Piriformis • Gluteus maximus	• Superior gemellus • Obturator externus • Vastus intermedius • Rectus femoris • Vastus lateralis	• Satorius • Gracilis • Vastus medialis • Adductor longus • Adductor magnus • Semimembra-nosus • Biceps femoris	• Tibialis anterior • Tibialis posterior • Peroneus • Extensor halluces • Extensor digitorum • Gastroc-nemius • Soleus

2.5.4 *Under and Over*

While receiving fire, Soldiers may be required to duck or vault over obstacles to find cover and concealment. For this event, Soldiers will duck under a 1.4-m hurdle and vault over a 0.9-m hurdle, placed on a 9.1-m course, while running as fast as possible. The U.S. Army stated that *Under and Over* measures upper- and lower-body muscular endurance, agility, postural stability, coordination, and speed stability.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are upper- and lower-body muscular endurance and postural stability.

Muscular involvement in the *Over and Under* is shown in Table 7 below.[42] The primary muscles for performing this event are gluteus maximus, vastus medialis, rectus femoris, sartorius, adductor longus, adductor magnus, semitendinosus, semimembranosus, gracilis, biceps femoris, gastrocnemius, and soleus. Metabolic analysis indicates that the primary energy system utilized is the phosphagen system, based on the duration of the event being less than six seconds.[34]

Table 7. Muscular Involvement in *the Over and Under*

Muscular Involvement in the Over and Under				
	Primary Movers		Accessory Muscles	
Upper Body			• Trapezius • Anterior deltoid • Medial deltoid • Posterior deltoid • Biceps brachii • Brachioradialis • Triceps brachii • Flexor digitorum	• Flexor carpi radialis • Extensor carpi radialis • Extensor digitorum
Trunk			• Obliquus externus • Obliquus internus • Rectus abdominis • Transversus abominis • Erector spinae	• Quadratus lumborum
Lower Body	• Gluteus maximus • Vastus medialis • Rectus femoris • Sartorius • Adductor longus • Adductor magnus • Semitendi-nosus	• semimembra-nosus • Gracilis • Biceps femoris • Gastrocnemius • Soleus	• Pectineus • Piriformis • Gluteus medius • Tibialis anterior • Tibialis posterior	

2.5.5 *Casualty Drag*

Soldiers may be required to move a casualty to a vehicle for transport. In the *Casualty Drag* event, Soldiers will grasp the handle of an 81.6-kg casualty rescue sled and drag it across a 9.1-m course and back, for a total distance of 18.3 m, as fast as possible. The U.S. Army stated that *Casualty Drag* measures total body muscular strength and endurance, agility, coordination, speed stability, and anaerobic power.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are total body muscular strength and endurance, and anaerobic power.

Muscular involvement in the *Casualty Drag* is shown in Table 8 below.[42] The primary muscles for performing this event are the anterior deltoid, medial deltoid, posterior deltoid, trapezius, infraspinatus, teres minor, teres, major, latismus dorsi, obliquus externus, obliquus internus, quadratus lumborum, erector spinae, gluteus medius, gluteus maximus, piriformis, sartorius, vastus intermedius, vastus medialis, rectus femoris, vastus lateralis, biceps femoris, semitendinosus, tibialis anterior, extensor hallucis, gastrocnemius, soleus, tibialis posterior, and flexor hallucis. Metabolic analysis indicates that the primary energy systems utilized are the phosphagen and fast glycolysis system, based on the duration of the event being six to 30 seconds.[34]

Table 8. Muscular Involvement in the *Casualty Drag*

	Muscular Involvement in the Casualty Drag			
	Primary Movers		Accessory Muscles	
Upper Body	• Anterior deltoid • Medial deltoid • Posterior deltoid • Trapezius • Infraspinatus • Teres minor • Teres major • Latismus dorsi		• Pectoralis major • Subscapularis • Coraco-brachialis • Brachioradialis • Biceps brachii • Triceps brachii • Extensor digitorum	• Flexor digitorum
Trunk	• Obliquus externus • Obliquus internus • Quadratus lumborum • Erector spinae		• Rectus abdominis • Transversus abominis	
Lower Body	• Gluteus medius • Gluteus maximus • Piriformis • Sartorius • Vastus intermedius • Vastus medialis • Rectus femoris • Vastus lateralis	• Biceps femoris • Semitendi-nosus • Tibialis anterior • Extensor halluces • Gastrocnemius • Soleus • Tibialis posterior • Flexor hallucis	• Pectineus • Adductor magnus • Adductor longus • Gracilis • Semimembra-nosus • Peroneus	

2.5.6 *Balance Beam Ammo Can Carry*

Soldiers may be required to move over obstacles while carrying equipment. For this event, Soldiers will carry one 13.6 kg ammo can in each hand while walking on three beams, each being 0.09 m wide and 1.8 m long, from one end to the other, and return to the starting point. Soldiers will attempt to walk as fast as possible while maintaining their balance throughout the event. The U.S. Army stated that *Balance Beam Ammo Can Carry* measures upper- and lower-body muscular endurance, agility, postural stability, coordination, and speed stability.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are upper- and lower-body muscular endurance and postural stability.

Muscular involvement in the *Balance Beam Ammo Can Carry* is shown in Table 9 below.[42] The primary muscles for performing this event are the trapezius, levator scapulae, rhomboid, gluteus maximus, vastus medialis, rectus femoris, sartorius, adductor longus, adductor magnus, semitendinosus, semimembranosus, gracilis, biceps femoris, gastrocnemius, and soleus. Metabolic analysis indicates that the primary energy systems utilized are the phosphagen and fast glycolysis system, based on the duration of the event being six to 30 seconds.[34]

Table 9. Muscular Involvement in the *Balance Beam Ammo Can Carry*

Muscular Involvement in the Balance Beam Ammo Can Carry				
	Primary Movers		Accessory Muscles	
Upper Body	• Trapezius • Levator scapulae • Rhomboid		• Sternocleido-mastoid • Splenius • Scalenes • Pectoralis major • Infraspinatus • Latissimus dorsi • Anterior deltoid • Medial deltoid • Teres minor • Teres major	• Biceps brachii • Brachialis • Brachioradialis • Triceps brachii • Flexor carpi radialis • Flexor digitorum • Extensor carpi radialis • Extensor digitorum
Trunk			• Obliquus externus • Obliquus internus • Rectus abdominis • Transversus abominis • Erector spinae	• Quadratus lumborum
Lower Body	• Gluteus maximus • Vastus medialis • Rectus femoris • Sartorius • Adductor longus • Adductor magnus	• Semitendi-nosus • Semimembra-nosus • Gracilis • Biceps femoris • Gastrocnemius • Soleus	• Pectineus • Piriformis • Gluteus medius • Tibialis anterior • Tibialis posterior	

2.5.7 *Point-Aim-Move*

Soldiers may be required to point, aim and engage targets while moving. For this event, Soldiers will point and aim a non-operational rifle at a target, shuffle laterally for 2.9 m, move backward, laterally, and then forward to clear a simulated wall, shuffle laterally for another 2.9 m, and return to the starting pointing utilizing the same method. Soldiers will attempt to move as fast as possible. The U.S. Army stated that *Point-Aim-Move* measures upper- and lower-body muscular endurance, agility, postural stability, coordination, and speed stability.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are upper- and lower-body muscular endurance and postural stability.

Muscular involvement in the *Point-Aim-Move* is shown in Table 10 below.[42] The primary muscles for performing this event are the trapezius, rhomboid, transversus abominis, gluteus maximus, vastus lateralis, rectus femoris, sartorius, adductor longus, and biceps femoris. Metabolic analysis indicates that the primary energy systems utilized are the phosphagen and fast glycolysis system, based on the duration of the event being six to 30 seconds.[34]

Table 10. Muscular Involvement in the *Point-Aim-Move*

Muscular Involvement in the Point-Aim-Move		
	Primary Movers	Accessory Muscles
Upper Body	• Trapezius • Rhomboid	• Anterior deltoid • Medial deltoid • Latissimus dorsi
Trunk	• Transversus abominis	• Obliquus externus • Erector spinae • Quadratus lumborum
Lower Body	• Gluteus maximus • Vastus lateralis • Rectus femoris • Sartorius • Adductor longus • Biceps femoris	• Gluteus medius • Tensor fasciae latae • Tibialis anterior • Extensor digitorum • Peroneus

2.5.8 *100-Yard Shuttle Sprint with Ammo Can*

Soldiers may be required to sprint to covered and concealed locations with equipment. For this event, Soldiers will carry one 13.6-kg ammo an in each hand while moving forward for 9.1-m, turn around at the end, and return to the starting point as fast as possible. Soldiers will repeat this cycle another 4 times, while covering a total distance of 91.4 m. The U.S. Army stated that the *100-Yard Shuttle Sprint with Ammo Can* measures total body muscular strength and endurance, agility, coordination, speed stability, and anaerobic power.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are total body muscular strength and endurance and anaerobic power.

Muscular involvement in the *100-Yard Shuttle Sprint with Ammo Can* is shown in Table 11 below.[42] The primary muscles for performing this event are the trapezius, levator scapulae, rhomboid, gluteus maximus, vastus medialis, rectus femoris, sartorius, adductor longus, adductor magnus, semitendinosus, semimembranosus, gracilis, biceps femoris, gastrocnemius, and soleus. Metabolic analysis indicates that the primary energy system utilized is the fast glycolysis system, based on the duration of the event being 30 seconds to two minutes.[34]

Table 11. Muscular Involvement in the *100-Yard Shuttle Sprint with Ammo Can*

Muscular Involvement in the 100-Yard Shuttle Sprint with Ammo Can				
	Primary Movers		Accessory Muscles	
Upper Body	• Trapezius • Levator scapulae • Rhomboid		• Sternocleido-mastoid • Splenius • Scalenes • Pectoralis major • Infraspinatus • Latissimus dorsi • Anterior deltoid • Medial deltoid • Teres minor • Teres major	• Biceps brachii • Brachialis • Brachioradialis • Triceps brachii • Flexor carpi radialis • Flexor digitorum • Extensor carpi radialis • Extensor digitorum
Trunk			• Obliquus externus • Obliquus internus • Rectus abdominis • Transversus abominis • Erector spinae	• Quadratus lumborum
Lower Body	• Gluteus maximus • Vastus medialis • Rectus femoris • Sartorius • Adductor longus • Adductor magnus	• Semitendi-nosus • Semimembra-nosus • Gracilis • Biceps femoris • Gastrocnemius • Soleus	• Pectineus • Piriformis • Gluteus medius • Tibialis anterior • Tibialis posterior	

2.5.9 *Agility Sprint*

Soldiers may be required to change direction rapidly while negotiating certain obstacles. During this event, Soldiers will sprint through a course that is 4.6 m wide and 9.1 m long while changing direction four times. The U.S. Army stated that *Agility Sprint* measures lower-body anaerobic capacity, speed, and anaerobic power.[10] The physical fitness components that can be measured safely and accurately in the Neuromuscular Research Laboratory are lower-body anaerobic capacity and anaerobic power.

Muscular involvement in the *Agility Sprint* is shown in Table 12 below.[42] The primary muscles for performing this event are the gluteus maximus, vastus lateralis, vastus intermedius, vastus medialis, rectus femoris, biceps femoris, and adductor magnus. Metabolic analysis indicates that the primary energy system utilized is the phosphagen system, based on the duration of the event being less than six seconds.[34]

Table 12. Muscular Involvement in the *Agility Sprint*

Muscular Involvement in the Agility Sprint	Primary Movers	Accessory Muscles	
Upper Body		• Trapezius • Anterior deltoid • Medial deltoid • Posterior deltoid • Biceps brachii • Brachioradialis • Triceps brachii • Flexor digitorum • Flexor carpi radialis	• Extensor carpi radialis • Extensor digitorum
Trunk		• Obliquus externus • Transversus abominis • Erector spinae • Quadratus lumborum	
Lower Body	• Gluteus maximus • Vastus lateralis • Vastus intermedius • Vastus medialis • Rectus femoris • Biceps femoris • Adductor magnus	• Iliopsoas • Sartorius • Tensor fasciae latae • Tibialis anterior • Extensor digitorium • Extensor halluces • Peroneus • Soleus	

2.5.10 Summary

The physical fitness components of the proposed ACRT that can be measured safely and accurately in the Neuromuscular Research Laboratory are listed in Table 13 below. Muscular endurance is weighted heavily, followed by the needs for agility, postural stability, anaerobic power and capacity, and muscular strength.

Table 13. Physical Fitness Components of the proposed Army Combat Readiness Test Measureable in the Neuromuscular Research Laboratory Based on Army Subject Experts' Opinion[10]

	Physical Fitness Components Measurable in NMRL					
	Muscular Strength	Muscular Endurance	Postural Stability	Anaerobic Power	Anaerobic Capacity	Agility
400 Meter Run		X			X	
Low Hurdle		X	X			X
High Crawl		X	X			X
Under and Over		X	X			X
Casualty Drag	X	X		X		X
Balance Beam Ammo Can		X	X			X
Point-Aim-Move		X		X		X
100-Yard Ammo Can	X	X		X		X
Agility Sprint				X	X	
Total Score	2	8	4	4	2	7

The primary muscles utilized in the proposed ACRT are shown in Table 14. The lower-body muscles are utilized the most, followed by upper-body and the trunk. In order to strengthen statistical power, the principal investigator will consider only the most-utilized muscles to be included in the test protocol. Although lower-body muscles are utilized more than those of the upper body and trunk, the principal investigator will consider one muscle for each body segment to be included in the test protocol, as several events in the proposed ACRT require strong upper-body, trunk, and lower-body muscular performance, and a combination of several muscular performance measurements may provide stronger prediction results.[43]

The most utilized upper-body muscle in the proposed ACRT is the trapezius. But the principal investigator is not aware of a reliable isokinetic muscular strength and endurance measurement for the trapezius. Shoulder rotator isokinetic muscular strength and endurance measurements have shown reliable results and can be easily replicated in the Neuromuscular Research Laboratory.[44] The proposed ACRT requires greater utilization of shoulder external rotators such as infraspinatus and teres minor, so shoulder external rotation isokinetic muscular strength and endurance test will be included in the test protocol.

The most utilized muscle in the trunk in the proposed ACRT is the obliquus externus and quadratus lumborum. The principal investigator is not aware of a reliable isokinetic muscular strength and endurance measurement for the quadratus lumborum. Only trunk rotation isokinetic muscular strength measurements have shown reliable results and can be easily replicated in the Neuromuscular Research Laboratory.[45] So, the trunk rotation isokinetic muscular strength test will be included in the test protocol.

The most utilized muscle in the lower body in the proposed ACRT is the gluteus maximus and rectus femoris. The principal investigator is not aware of a reliable isokinetic muscular strength and endurance measurement for the gluteus maximus. However, knee flexion and extension isokinetic muscular strength and endurance measurements have shown reliable results and can be easily replicated in the Neuromuscular Research Laboratory.[44, 46] As the rectus femoris is a knee extensor, the knee extension isokinetic muscular strength and endurance test will be included in the test protocol.

Table 14. Primary Muscle Utilization in the Proposed Army Combat Readiness Test

Upper Body		Trunk		Lower Body	
Primary Muscles	Percentage (%)	Primary Muscles	Percentage (%)	Primary Muscles	Percentage (%)
Trapezius	55.56	Obliquus externus	22.22	Gluteus maximus	100.00
Rhomboid	44.44	Quadratus lumborum	22.22	Rectus femoris	100.00
Levator scapulae	22.22	Transversus abominis	11.11	Biceps femoris	88.89
Posterior deltoid	22.22	Obliquus internus	11.11	Vastus medialis	77.78
Infraspinatus	22.22	Erector spinae	11.11	Adductor magnus	66.67
Teres major	22.22			Sartorius	66.67
Latissimus dorsi	22.22			Adductor longus	55.56
Teres minor	11.11			Vastus lateralis	55.56
Biceps brachii	11.11			Semitendinosus	55.56
Brachialis	11.11			Gastrocnemius	55.56
Brachioradialis	11.11			Soleus	55.56
				Vastus intermedius	44.44
				Semimembranosus	44.44
				Gracilis	44.44
				Gluteus medius	22.22
				Piriformis	22.22
				Gluteus minimus	11.11
				Tensor fasciae latae	11.11
				Tibialis anterior	11.11
				Tibialis posterior	11.11
				Extensor hallucis	11.11
				Flexor hallucis	11.11
				Superior gemellus	11.11
				Obturator externus	11.11

The primary energy systems utilized in the proposed ACRT, presented in percentage of all nine events, are mainly a combination of the phosphagen and fast glycolysis systems (44.44%), followed by the phosphagen system (33.33%), and the fast glycolysis system (22.22%). The reliance on the phosphagen and fast glycolysis systems indicates that anaerobic power and anaerobic capacity are better predictors for the proposed ACRT performance.[34]

The preliminary test protocol thus includes shoulder external rotation, knee extension muscular strength and endurance, trunk rotation muscular strength, postural stability, anaerobic power and capacity, and body composition. Further refinement of the test variables will be discussed in the following section.

2.6 METHODOLOGICAL CONSIDERATIONS

Based on the needs analysis in the previous section, muscular strength and endurance, anaerobic power and capacity, postural stability, and agility are the physical fitness components of the proposed ACRT that can be measured in the Neuromuscular Research Laboratory. However, a complete athletic performance assessment also includes aerobic capacity, speed, flexibility, and body composition.[34] Fat-free mass may also play a significant role.[27, 36, 47] Speed cannot be assessed safely in the Neuromuscular Research Laboratory due to the space limitations. Thus, further consideration of including aerobic capacity, flexibility, body composition, and fat-free mass as well as previous variables in this study, will be discussed in this section.

2.6.1 Subject Population

The proposed ACRT incorporates many soldiering tasks that may not be practiced by general populations. Studies have also shown significant differences in musculoskeletal, neuromuscular, and physiological characteristics between genders,[48-51] which may negatively impact the ability to predict the dependable variable. In order to control variability in the proposed ACRT performance due to gender and familiarity with the movement skills required by the soldiering tasks, the principal investigator opts for recruiting male subjects with military experience only.

2.6.2 Muscular Strength

Muscular strength is defined as the capacity of a muscle or muscle group to produce tension, regardless of the testing mode with which it is measured.[52] Muscular strength has been demonstrated to be critical to many athletic activities, including military performance.[29, 34] Isokinetic muscular strength performance has also been shown to correlate to sports performance.[53-56] To the principal investigator's knowledge, there have been no studies examining the relationship between isokinetic muscular strength and military performance.

Muscular strength can be measured using force transducers in isometric exercises, 1-repetition maximum (1RM) testing during the bench press or back squat, or isokinetic dynamometers in isokinetic exercises.[34] The isometric mode is the easiest to perform, but may not be ideal for testing athletes due to its static nature. The 1RM testing allows testing in movement patterns similar to sport activities, but is not ideal for scientific purposes. Subjects' performance is limited by the weakest point in their joint range of motion, and can be heavily influenced by their techniques and skills.[52] The isokinetic mode has been the standard for assessing muscular strength in both clinical and research settings.[57] The isokinetic mode enables subjects to apply maximum force throughout their joint range of motion at a predetermined speed, and has been shown to be highly reliable.[52] However, the equipment required for isokinetic muscular strength assessment is expensive and needs well-trained personnel to operate, as well as more time to set up than do the other options.[52]

The isokinetic muscular strength test can be assessed by having subjects perform maximum reciprocal contractions of agonist and antagonist muscles at 30°/sec to 300°/sec.[52] The results can be reported as: 1) peak torque, 2) average peak torque, 3) peak torque normalized by body weight, 4) angle-specific torque, 5) time to peak torque, 6) torque-velocity ratio, 7) angle of occurrence, 8) total work, 9) peak power and average power, 10) peak torque acceleration energy, and 11) endurance ratios.[52] For this study, the principal investigator opts to use an angular velocity of 60°/sec and report results in average peak torque as they have been shown to be reliable.[45, 58, 59]

Dominant shoulder external rotation, torso rotation to the non-dominant side, and dominant knee extension muscular strength tests were considered to be included in the test protocol based on the needs analysis. Shoulder external rotation average peak torque reliability has been previously reported in the literature (ICC = 0.74–0.87, SEM = 9–13).[58] Knee extension average peak torque reliability has been previously reported in the literature (ICC = 0.76–0.86, SEM = 5.1–7.5).[59] Torso rotation average peak torque reliability has also been previously reported in the literature (ICC = 0.93, SEM = 7.70–8.12).[45] Only the dominant side will be tested or analyzed because studies have shown that people do not exhibit limb dominance in shoulder rotation, knee, and trunk rotation muscular strength and endurance unless they engage in regular activities involving only one side of the limbs.[45, 60, 61] Soldiers' tasks, such as crawling, running, and climbing, often involve both limbs, so it is unlikely they will exhibit limb dominance in muscular strength or endurance.

Although dominant shoulder external rotation, torso rotation to the non-dominant side, and dominant knee extension muscular strength tests are important measurements, they are all significantly correlated according to 399 Army 101st Airborne Soldiers' data ($r = 0.213, 0.390, 0.544$; $p < 0.01$). In addition, lower-body muscles are utilized more as mentioned in the previous section. In order to meet the assumptions for multiple regression analysis and keep the test protocol within a reasonable time span, the principal investigator opts for testing dominant knee extension muscular strength only.

2.6.3 Muscular Endurance

Muscular endurance is defined as the capacity of a muscle or muscle group to contract repeatedly against a submaximal load for a prolonged period.[52] Muscular endurance has been shown to be important to many athletic activities, including military performance.[29, 34] To the principal investigator's knowledge, there have been no studies examining the relationship between isokinetic muscular endurance and sports, nor between isokinetic muscular endurance and military performance.

Muscular endurance can be measured by the maximum number of repetitions in body weight exercises such as push-ups and sit-ups, the maximum number of repetitions with a submaximal load, or isokinetic dynamometers in isokinetic exercises.[34] The measurement of muscular endurance using body weight exercises is the easiest to administer and perform, but the number of muscle groups that can be measured is limited. The advantages and disadvantages of measuring muscular endurance using a submaximal load and isokinetic exercises have been mentioned in previous section.

Isokinetic muscular endurance can be assessed by having subjects perform 25–30 maximum reciprocal contractions of agonist and antagonist muscles at 180°/sec or 240°/sec[45, 46, 62, 63] or as many as possible in a 45-second period. The results can be interpreted as: 1) peak torque, 2) torque acceleration energy, 3) total work, 4) work done in the first five contractions, 5) work done during the last five contractions, 6) average power, 7) work ratio, and 8) number of contractions until peak torque fall to 50% of initial peak torque.[46] Burdett et al.[46] showed total work performed by maximally contracting agonist and antagonist muscles 25 times at 180°/sec as the most reliable measurement (ICC = 0.91–0.98), and that will be utilized in this study.

Dominant shoulder external rotation, torso rotation to the non-dominant side, and dominant knee extension muscular endurance tests were considered to be included in the test protocol based on the needs analysis. Shoulder external rotation total work reliability has been previously reported in the literature (r = 0.83–0.89).[44] Knee extension total work reliability has been previously reported in the literature (ICC = 0.91–0.98).[44, 46] Torso rotation muscular endurance test reliability has not been reported in the literature.[45] Only the dominant side will be tested or analyzed because studies have shown that people do not exhibit limb dominance in shoulder rotation, knee, and trunk rotation muscular strength and endurance unless they engage in regular activities involving only one side of the limbs.[45, 60, 61] Soldiers' tasks often involve both limbs, such as crawling, running, and climbing, so it is unlikely they will exhibit limb dominance in muscular strength and endurance.

Although dominant shoulder external rotation, torso rotation to the non-dominant side, and dominant knee extension muscular endurance tests are important measurements, the principal investigator opts for testing dominant shoulder external rotation only.[64] Murphy et al. showed lower-extremity isokinetic muscular endurance had strong correlations with lower extremity anaerobic capacity.[64] There have been no studies examining the reliability of torso rotation muscular endurance tests.

2.6.4 Postural Stability

Postural stability is defined as the ability to maintain a fixed position or a desired movement pattern despite internal or external perturbation.[65] Postural stability has been shown to be important to many athletic activities, including military performance.[66, 67] To the principal investigator's knowledge, there have been no studies examining the relationship between dynamic postural stability and sports, nor between dynamic postural stability and military performance. The ability to maintain a fixed position is referred as static postural stability, while the ability to maintain a movement pattern is referred as dynamic postural stability.[65] Dynamic postural stability assessment requires subjects to divert conscious attention to the execution of activities such as jumping and running, and may be more sensitive in detecting postural control deficits for athletic populations. [65, 68]

Dynamic postural stability can be measured using clinical- and apparatus-based methods.[65, 68] Clinical-based methods such as the star-excursion test can be done in the field without expensive equipment, but apparatus-based methods using force plates or other devices may be more sensitive to small differences.[65, 68, 69]

Dynamic postural stability assessments utilizing single-leg jump landing tasks have been shown to have reliable measurements (ICC = 0.86–0.92, SEM = 0.01).[65] Dynamic postural stability assessments will be conducted on the dominant limb. Studies have shown few differences between limbs in postural stability.[70, 71] The specific variables to be analyzed are the dynamic postural stability index.

2.6.5 Aerobic Capacity

Aerobic capacity is defined as the ability of muscles to utilize oxygen to produce energy.[34] Aerobic capacity has been shown to be critical to many aerobic endurance sports events as well as military performance.[6, 28, 29, 34, 41]

Aerobic capacity is typically assessed by maximal oxygen uptake, which can be measured directly with a metabolic device or estimated with field tests such as timed or set-distance runs or timed swimming or cycling. It can also be estimated with multi-stage treadmill or cycle ergometer tests.[72, 73] For this study, the principal investigator opts for direct measurement in a laboratory for accuracy.

Aerobic capacity can be measured with a variety of protocols involving different initial intensity, workload increment, or exercise modes.[73] A protocol lasting eight to twelve minutes is recommended for trained athletes, as it elicits higher maximal oxygen uptake results.[74] Some other popular protocols, such as the Balke protocol, may require significantly longer test duration and thus underestimate subjects' maximal oxygen uptake.[73] As the subjects in this study will be considered trained athletes, the principal investigator opts to use a modified Astrand protocol in order to attain the targeted test duration.[75] In addition, the treadmill will be used for testing instead of the bicycle ergometer, as running is more specific to the activities of the subject population.[73]

2.6.6 Anaerobic Capacity

Anaerobic power is defined as the ability of the muscles to produce high force while contracting at a high speed, while anaerobic capacity refers to the ability to produce power between thirty and ninety seconds of maximal effort.[34] Anaerobic power and capacity have been shown to be critical to many athletic activities, including military performance.[6, 28, 29, 34, 41]

The measurements of anaerobic power and capacity are specific to the needs of the sports or activities, and different tests are not interchangeable.[34, 73] Anaerobic power can be measured using explosive exercises such as the power clean, vertical jump, and stair sprint. Anaerobic capacity can be measured using short-duration exercises between thirty to ninety seconds, such as the Wingate bicycle ergometer protocol and shuttle run.[34, 73] The Wingate Anaerobic Test is the gold standard for anaerobic power and capacity measurements, and its validity and reliability have been well documented.[34, 73] Thus, the principal investigator opts to use the Wingate Anaerobic Test for this study.

Anaerobic power and capacity are the two major variables produced from the Wingate Anaerobic Test.[34, 73] Anaerobic power is the highest power produced during the first five seconds of the test, while the anaerobic capacity is the average of the power produced during the entire thirty seconds of the test.[75, 76] Both anaerobic power and capacity are important measurements, as they are both significantly correlated according to 393 Army 101st Airborne Soldiers' data ($r = 0.607$; $p < 0.01$). In order to meet the assumption for multiple regression analysis, the principal investigator opts to include anaerobic capacity in the analysis only.

2.6.7 Flexibility

Flexibility is defined as the degree of range of motion available in a body joint.[34] The role of flexibility in athletic performance is sport- and joint-specific.[72, 73] For example, baseball pitchers require twice as much shoulder external rotation as do athletes in other sports,[77] while long-distance runners need less ankle dorsiflexion for better running economy than do other types of runners.[78] Flexibility has also been shown to be important to military performance.[31]

Flexibility can be assessed with motion-capture systems, goniometers, a tape measure, or sit-and-reach boxes.[73] Motion-capture systems provide the capability for accurate assessment of athletes' flexibility while performing athletic tasks, but might not show the maximum range of motion that the athletes are capable of achieving.[73] Active or passive range of motion tests using goniometers or tape measures have high validity and reliability, but are not ideal for assessing flexibility during athletic tasks.[73] Active or passive range-of-motion tests can only assess one joint at a time, but athletic tasks usually involve movement in multiple joints and may require lengthy test sessions to provide results.[73] The sit-and-reach test has been utilized for assessing the composite flexibility of the hip and lumbar joints.[72] It is reliable and widely used in various populations and studies (ICC = 0.94).[79, 80] The sit-and-reach test, when combined with body weight, bench press, and hang-clean performance, can predict shuttle run performance.[81] Although there is not a single test that can represent the flexibility of all the joints in a human body,[72] the sit-and-reach test may be an acceptable choice for keeping the test protocol within reasonable time span.[81] Thus, the principal investigator opts to use the sit-and-reach test for testing flexibility.

2.6.8 Body Composition

Body composition is defined as the weight ratio between body fat and fat-free tissues.[72] Body composition has been shown to be paramount to athletic success, including military performance.[29] Optimal body composition is specific to sports and to specific positions within each sport.[82] Sports that categorize athletes by weight, or require exceptional anaerobic or aerobic performance, such as wrestling, the 100-meter run, and marathons, tend to favor athletes with low body fat.[83] In contrast, athletes attending low-impact sports, such as kayaking and swimming, tend to have higher body fat.[83] On the other hand, athletes participating in some team sports, such as football, usually exhibit a variety of body fat by position.[82]

Body composition can be assessed with girth measurements, skin fold measurements, near-infrared interactance, bioelectrical impedance analysis, hydrodensitometry, dual-energy x-ray absorptiometry, computed tomography scans, magnetic resonance imaging, and air displacement plethysmography.[73] Girth measurements and near-infrared interactance are the least accurate of these.[73] Bioelectrical impedance analysis tends to produce a greater degree of error from many confounding variables.[73] Skin fold measurements are a valid and reliable measurement when done with a skilled tester, but can produce greater degree of error with untrained testers.[72, 73] Dual-energy x-ray absorptiometry, computed tomography scans, and magnetic resonance imaging can provide very accurate measurements, but the measurement equipment is very expensive and usually available only in large medical facilities.[73] Hydrodensitometry is considered the gold standard for body composition analysis, but it requires a lengthy test protocol and frequent equipment maintenance.[34] Air displacement plethysmography utilizes the same principle as hydrodensitometry, and has been shown to be valid and reliable.[84-86] Intra-session reliability has been demonstrated in the Neuromuscular Research Laboratory (ICC = 0.98, SEM = 0.47 body fat percentage).[76] Its reliability has also been shown in tests across a variety of populations.[86] For this study, the principal investigator opts to use air displacement plethysmography for its accuracy and practicality.

2.6.9 Fat-free Mass

Fat-free mass is defined as the mass of the fat-free tissues in a human body.[72] Fat-free mass has been shown to be critical to many athletic activities, including military performance.[27, 36, 47] Sports involving lifting and carrying external loads require greater fat-free mass.[27, 35, 36, 87] However, sports emphasizing moving athletes' own body mass through space do not seem to be associated with fat-free mass.[88, 89] Fat-free mass is usually part of the body composition assessment, thus its methodological consideration is the same as Section 2.6.8.

2.6.10 Agility

Agility is defined as the ability to start, stop, and change direction of one or more body parts.[34] Agility plays an important role to most sports, such as American football, ice hockey, soccer and tennis.[73] Only some sports, such as track and swimming, involve minimal or no change of direction and thus do not require agility.[73] Agility has also been considered critical for military performance.[8-10]

Agility can be easily assessed with just a stopwatch, but better accuracy can be achieved with the use of timing gates.[73] For this study, the principal investigator opts to utilizing timing gates for accuracy. Agility can also be measured with numerous protocols, such as the Pro-Agility, T-test, Three-Cone, 505, and Illinois agility test.[90] The Pro-Agility, T-test, Three-Cone, 505, and Illinois agility test have all been shown to be valid and reliable tests (ICC = 0.88 – 0.95, SEM = 0.06 – 0.39).[90] Pro-Agility, T-test, Three-Cone, 505, and Illinois agility test are also strongly correlated (r = 0.84 - 0.89), suggesting that these tests all assess the same physical capability.[90] Considering the Pro-Agility requires the least amount of space and is easy for subject to master, the principal investigator opts to use the Pro-Agility to assess agility.

2.6.11 Summary

For this study, only male subjects with military experience will be recruited. The test protocol will include measurements of muscular strength and endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility. The variables to be included in multiple regression analysis are listed in Table 15 below.

Table 15. Variables Selected for Multiple Regression Analysis

Variables Selected for Multiple Regression Analysis	
Physical Fitness Components	Variables
Muscular Strength	Average peak torque performed by dominant knee extension normalized by bod mass (Nm/kg)
Muscular Endurance	Total work performed by dominant shoulder external rotation normalized by body mass (J/kg)
Postural Stability	Dynamic postural stability index during a two-legged jump and on-legged landing task
Aerobic Capacity	Maximal oxygen uptake normalized by body mass (mL/kg/min)
Anaerobic Capacity	Average peak power normalized by body mass (watts/kg)
Flexibility	Sit-and-reach distance (cm)
Body Composition	Percent body fat
Fat-free Mass	Mass of fat-free tissues (kg)
Agility	Time to completion (s)

3.0 METHODOLOGY

The methodology section begins with description of experimental design, as well as independent and dependent variables. Next, subject populations and recruitment method, as well as inclusion and exclusion criteria are presented. The required subject number for this study are shown in the power analysis section. Furthermore, details of the instrumentations and test protocols are elucidated. Methods of data summarizations and calculations are then depicted, followed by presentation of the statistical methodology.

3.1 EXPERIMENTAL DESIGN

A cross-sectional research design was used. There were two test sessions in this study. The field test session was held in an indoor field, and the laboratory test session was held in the Neuromuscular Research Laboratory of the Department of Sports Medicine and Nutrition at the University of Pittsburgh. The field test session produced the dependent variable, and the laboratory test session produced the independent variables shown below. A step-wise multiple regression analysis was utilized to determine the ability of the independent variables to predict the dependent variable.

Independent Variables

- Muscular strength: average peak torque performed by dominant knee extension normalized by body mass during an isokinetic knee extension/flexion strength assessment (Newton-meters/kilogram)
- Muscular endurance: total work performed by dominant shoulder external rotation normalized by body mass during an isokinetic shoulder internal/external rotation strength assessment (Joules/kilogram)
- Postural stability: dynamic postural stability index during a two-legged jump and on-legged landing task
- Aerobic capacity: Maximal oxygen uptake (VO_2 max) normalized by body mass during a graded treadmill running assessment (milliliters/ kilogram/minute)
- Anaerobic capacity: average peak power normalized by body mass during a 30-second Wingate protocol (watts/kg)
- Flexibility: sit-and-reach distance during a sit-and-reach assessment (centimeters)
- Body composition: percent body fat during a BOD POD assessment (percent body fat)
- Fat-free mass: mass of fat-free tissues (kilogram)
- Agility: the fastest time to completion of two Pro Agility tests (seconds)

Dependent Variable

- Time to completion of the proposed Army Combat Readiness Test (seconds)

3.2 SUBJECT RECRUITMENT

Forty-four subjects were screened and enrolled in this study. One subject failed to return for the follow-up test, and his remaining data were excluded from analyses. A total of forty-three subjects completed both testing sessions. Twenty-eight subjects were males with military experience, including active duty and reserve duty Soldiers and National Guard and Reserve Officers' Training Corps (ROTC) members. Later, fifteen subjects without military experience were enrolled in this study due to lack of response to recruitment from military population. The change in inclusion criteria was approved by the dissertation committee as well as the Institutional Review Board of the University of Pittsburgh. The principal investigator contacted the Office of Veterans Services and the ROTC at the University of Pittsburgh for assistance in subject recruitment. In addition, the principal investigator posted flyers in permitted areas in the communities around the University of Pittsburgh. Potential subjects contacted the principal investigator and underwent a phone screen to determine their eligibility. Subjects who were eligible and agree to participate were then scheduled for a laboratory and a field test session.

3.3 SUBJECT CHARACTERISTICS

3.3.1 Inclusion Criteria

Subjects were included in this study if they were males between the ages of 18 and 30 who participate in regular physical training at least five days per week for at least 60 minutes per session.

3.3.2 Exclusion Criteria

Subjects were excluded from this study if they were female or did not meet the inclusion criteria. They were also excluded if they had signs of significant limitation of extremities or torso motion or postural deformity; had symptoms of vertigo or dizziness; had a history of previous surgery on the extremities or spine, neurological disorders, extremity injury such as tendonitis, dislocation, instability, and bursitis within the past six months, or back injury such as disc pathology, fracture, instability, or muscle strain within the past six months.

As the proposed Army Combat Readiness Test requires subjects to perform maximum exertion, subjects were also excluded if they had medical conditions that contraindicate participation. The principal investigator utilized the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) during the phone screening to exclude subjects with such conditions.[91]

3.4 POWER ANALYSIS

Sample size was calculated using the G*Power 3.1 statistical analysis program.[92] Based on the study of Bishop et al.,[28] $R^2 = 0.40$ is chosen for power analysis. Using an alpha level of $\alpha = 0.05$, power of $P = 0.80$, $R^2 = 0.40$, and 9 predictor variables, a total of 40 subjects were needed. To accounting for 10% attrition rate, up to 4 additional subjects were enrolled.

3.5 INSTRUMENTATION

3.5.1 Freelap Timing System

Time to completion of the proposed Army Combat Readiness Test and Pro-Agility was measured using the Freelap Timing System (Freelap, Fleurier, Switzerland). The Freelap Timing System consists of two electromagnetic devices positioned at the beginning and end of a course, and a wristwatch that utilizes the proximity to the electromagnetic rods to start and stop timing. The Freelap Timing System provides accuracy to 2/100^{ths} second.

3.5.2 Polar Heart Rate Monitor

Heart rate was measured and recorded using a Polar RS400 Training Computer, Polar WearLink+ transmitter, and Polar ProTrainer 5 software (Polar USA, Lake Success, NY). The Polar heart rate monitor has been demonstrated to have excellent agreement with the electrocardiogram system (ICC = 0.996).[93]

3.5.3 BOD POD Body Composition System

Body composition was measured using the BOD POD Body Composition System (Life Measurement Instruments, Concord, CA). The BOD POD system consists of an egg-shaped capsule with two chambers (reference and test), a weight scale, and a computer station. The BOD POD system utilizes air displacement plethysmography, which has been demonstrated to correlate highly with hydrostatic weighing (r = 0.96) and dual-energy X-ray absorptiometry (r =

0.90).[84, 85] The calibration of the BOD POD system was performed before each test using a 50.401-liter cylinder for the test chamber and a standard 20-kilogram weight for the weight scale.

3.5.4 Kistler Force Platform

The dynamic postural stability index in the anterior-posterior jump was calculated from the ground reaction force data collected with a Kistler 9286A (Kistler Instrument Corp., Amherst, NY) piezoelectric force platform. The Kistler force platform is interfaced and synchronized with the Vicon MX system (Vicon Motion Systems, Inc., Centennial, CO) with a built-in analog to digital (A/D) converter board. All data will be recorded using the Vicon Nexus Motion Analysis System Software Version 1.3 (Vicon Motion Systems, Inc., Centennial, CO). Ground reaction force data were collected at 1200 Hz during the dynamic postural stability assessment. The piezoelectric force platform is considered the gold standard for postural stability measurement and has been shown to be valid and reliable.[94] The Kistler force platform was reset to zero before each measurement.

3.5.5 Biodex Isokinetic Dynamometer

Average peak torque by dominant knee extension and total work performed by dominant shoulder external rotation was measured with the Biodex System III Multi-Joint testing and Rehabilitation System (Biodex Medical Systems, Inc., Shirley, NY). The Biodex system consists of an adjustable chair and dynamometer, as well as a computer station. The controller software – the Biodex Advantage Software Version 3.4 (Biodex Medical Systems, Inc., Shirley, NY) – automatically adjusted the torque values for gravity. The Biodex system has been demonstrated to be valid (ICC = 0.99) and reliable (ICC = 0.99–1.00; SEM = 0.00–12.89) in all measurements.[95] The calibration of the Biodex dynamometer was performed according to the specifications outlined by the manufacturer's service manual.

3.5.6 Velotron Cycling Ergometer

Anaerobic capacity was measured utilizing the Velotron cycling ergometer (RacerMate, Inc., Seattle, WA). The braking resistance on the Velotron cycling ergometer is controlled by Velotron Wingate Version 1.0.1(RacerMate, Inc., Seattle, WA). The Velotron has been demonstrated to be reliable (ICC = 0.70–0.90; SEM = 0.18–3.13).[96] The Velotron was calibrated before testing to ensure that wattage output is within one percent deviation from the factory setting.

3.5.7 ParvoMedics Metabolic Unit

Maximal oxygen uptake was measured with the ParvoMedics TrueOne 2400 (ParvoMedics, Sany, UT). ParvoMedics TrueOne 2400 consists of a breathing mask an air mixing chamber, and a computer station. Calibration and data collection were performed using the ParvoMedics TrueOne Metabolic System OUSW 4.3.4 (ParvoMedics, Sandy, UT). The ParvoMedics TrueOne 2400 has been demonstrated to be valid and reliable (CV = 4.7–5.7%).[97] The ParvoMedics TrueOne 2400 was calibrated before testing to ensure that oxygen, carbon dioxide, and air flow measurement variations were within one percent.

3.5.8 Lactate Pro Lactate Measurement System

The Lactate Pro Analyzer (Cycle Classic Imports, Carlton, Australia) was utilized to measure blood lactate concentration during the aerobic capacity assessment. The Lactate Pro Analyzer consists of a compact reader and disposable analyzer chips. It has been demonstrated to be a valid (CV = 8.9; SEE = 1.1) and reliable (CV = 5.7; TE = 5.7) portable blood lactate analyzer.[98] Calibration was performed using the calibration chips.

3.5.9 Novel Flex-tester Sit-and-reach Box

Flexibility was measured with the Novel Flex-tester sit-and-reach box (Novel Products Inc, Rockton, IL). The Novel Flex-tester sit-and-reach box consists of a metal platform with scales printed on top. It has been demonstrated to be reliable (ICC = 0.94).[80]

3.6 TESTING PROCEDURES

3.6.1 Subject Preparation

The principal investigator gave a written informed consent form, approved by the Institutional Review Board of the University of Pittsburgh, to each subject prior to participation. The principal investigator explained the contents of the informed consent form to each subject, and the subjects were given ample time to read and ask questions. After the subjects had their questions answered and gave informed consent, the principal investigator verified inclusion and exclusion criteria before enrolling the subjects.

3.6.2 Order of Testing

Subjects reported for two sessions for this study. The laboratory test session, which was the first session, was held in the Neuromuscular Research Laboratory of the Department of Sports Medicine and Nutrition at the University of Pittsburgh. The field test session, which was second session, was held on an indoor football field approximately 110 m long and 48 m wide. Sessions were separated by a minimum of 48 hours to ensure full recovery and prevent potential confounding results on subsequent tests. Subjects were asked to wear a long-sleeved shirt, pants, and running shoes; a Freelap wristwatch; a heart rate monitor; and an Advanced Combat Helmet; and carry a weighted PVC pipe similar to the size and weight of an M4 rifle for the field test session. The principal investigator provided the Freelap wristwatch, the heart rate monitor, the helmet, and the rifle simulator.

The laboratory testing was conducted in the following order: body composition and fat-free mass, flexibility, agility, dynamic postural stability, knee muscular strength, shoulder muscular endurance, anaerobic capacity, and aerobic capacity. Subjects were asked to wear exercise shorts, a shirt and running shoes.

3.6.3 Army Combat Readiness Test

The proposed ACRT is a circuit course (Figure 1) comprised of the following nine events performed in continuous and sequential order: 1) *400-Meter Run*, 2) *Low Hurdles*, 3) *High Crawl*,

4) *Under and Over*, 5) *Casualty Drag*, 6) *Balance Beam Ammo Can Carry*, 7) *Point-Aim-Move*, 8) *100-Yard Shuttle Sprint with Ammo Can*, and 9) *Agility Sprint*. During the proposed ACRT, subjects were asked to complete the circuit course as quickly as possible while wearing a long-sleeved shirt, pants, and running shoes, a heart rate monitor, a Freelap wristwatch, and an Advance Combat Helmet, while carrying a weighted PVC pipe similar to the size and weight of an M4 rifle. Subjects were familiarized with the test and instructed to complete the proposed ACRT twice with their best effort as practice. Subjects then completed the official timed event. A minimum rest period of five minutes was allotted between each trial. The time taken to complete the circuit course, average heart rates, and rate of perceived exertion were recorded after each practice and actual tests.

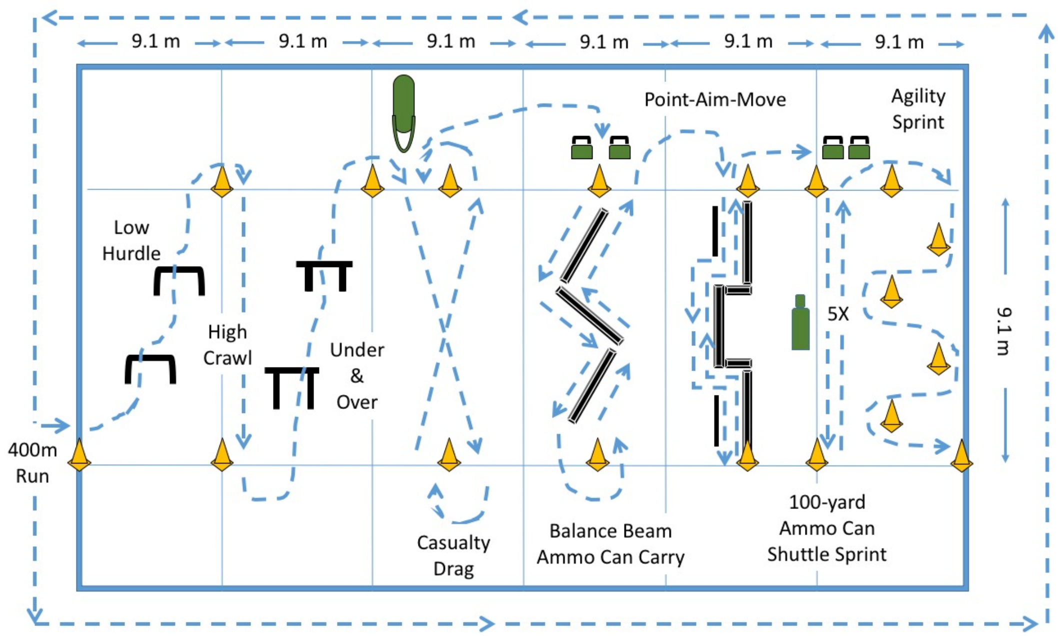


Figure 1. Army Combat Readiness Test

Subjects began by straddling a Freelap timing device using a three-point stance. Subjects used their right thumb to push down a button on the Freelap timing device on the ground, and began the proposed ACRT by releasing the button at their own discretion. The *400-Meter Run* (Figure 2) was performed on a predetermined and marked route directly leading into the next event, the *Low Hurdles*. Subjects were asked to negotiate two 0.5-m hurdles placed 1.8 m apart during a straightforward 9.1-m run (Figure 3). If subjects knocked over any hurdles, they were asked to reposition the hurdles and negotiate them again. The timing still continued during the failed attempt, and it was included in the total time to completion.

Figure 2. *400-Meter Run*

Figure 3. *Low Hurdle*

The *High Crawl* (Figure 4) followed with subjects assuming a position on their bellies and proceeding with tactical movement to cover a distance of 9.1 m. During the *High Crawl* subjects must maintain four points of contact with the ground at all times, leading into the *Under and Over* (Figure 5) event. Subjects were instructed to negotiate the high hurdle by moving under the hurdle and negotiate the low hurdle by maneuvering over the hurdle. The hurdles for this event were placed 3.7 m apart and measure 1.4 m and 0.9 m in height, respectively. If subjects knocked over any hurdles, they were asked to reposition the hurdles and negotiate them again. The timing still continued during the failed attempt, and it was included in the total time to completion.

Figure 4. *High Crawl*

Figure 5. *Under and Over*

The next event was the *Casualty Drag* (Figure 6) during which subjects were instructed to drag an 81.6-kg casualty rescue sled in a figure eight pattern around two cones placed 9.1 m apart. To successfully negotiate the cones the subjects must complete the *Casualty Drag* without contacting the cones. If subjects knocked over any cones, they were asked to reposition the cones and continue the event. The timing still continued during the failed attempt, and it was included in the total time to completion.

Figure 6. *Casualty Drag*

After successful completion of the *Casualty Drag*, subjects carried out the *Balance Beam Ammo Can Carry* (Figure 7). Subjects were instructed to carry a 13.6-kg ammunition can in each hand while negotiating fixed balance beams 0.1 m in height. Three separate beams 0.1 m wide and 1.8 m in length were placed in a “Z” pattern. Subjects were instructed to negotiate the beams without touching down in one direction, step down to turn around, and negotiate the beams back to the original starting position. If subjects inadvertently stepped off the beam to regain balance, they were instructed to step back on to the beam and regain balance before continuing to negotiate the obstacle. The timing still continued during the failed attempt, and it was included in the total time to completion. Once complete, subjects placed the ammunition cans on the ground and proceed to the *Point-Aim-Move* (Figure 8) event. During the *Point-Aim-Move* event subjects pointed the weighted PVC pipe in a firing position as though to engage a target, laterally shuffled to their right 2.9 m while continuing to point at the target, disengaged the target while back pedaling 0.9 m, laterally shuffled to their right 0.9 m, re-engaged the target while stepping forward 0.9 m, laterally shuffled to their right 2.9 m, and reversed direction while completing the same sequence of *Point-Aim-Move* back to the original start position.

Figure 7. *Balance Beam Ammo Can Carry*

Figure 8. *Point-Aim-Move*

Next, subjects were instructed to complete the *100-Yard Shuttle Sprint with Ammo Can* (Figure 9). Subjects performed five 18.3-m up-backs while carrying a 13.6-kg ammunition can in each hand. After completing the *100-Yard Shuttle Sprint with Ammo Can*, subjects were instructed to place the ammunition cans on the ground before proceeding to the final obstacle. The final obstacle, the *Agility Sprint* (Figure 10), was performed by sprinting around six cones placed in an "S" pattern covering a 4.6 x 9.1-m area.

Figure 9. *100-Yard Shuttle Sprint with Ammo Can*

Figure 10. *Agility Sprint*

3.6.4 Body Composition Assessment

Subjects were required to wear a tight-fitting bathing suit or spandex outfit with a swim cap covering their hair to reduce air impedance. Calibration consisted of placing an object of known weight on the scale and an object of known volume into the structure to assure maximum accuracy. Total calibration time was approximately two to three minutes. Subjects stood on the scale to have their body weight taken, entered the BOD POD and sat within the system for approximately one minute (Figure 11). Subjects breathed regularly and remained motionless during the testing procedure. The specific variable to be analyzed were body fat percentage and fat-free mass.

Figure 11. BOD POD Body Composition Assessment

3.6.5 Flexibility Assessment

Subjects sat without shoes and keep their knees straight and soles flat against the sit-and-reach box (Figure 12). Subjects were asked to slowly reach forward with both hands as far as they can and hold this position for two seconds. During the forward reach, subjects were reminded to keep their hands parallel to each other and knees in full extension. Three successful trials were collected, and the best was recorded.

Figure 12. Flexibility Assessment

3.6.6 Agility Assessment

Subjects straddled the middle line of three parallel lines five yards (4.57 meters) apart using a three-point stance. Subjects used their right thumb to push down a button on the Freelap timing device on the ground, and began the Pro-Agility by releasing the button at their own discretion. Subjects sprinted five yards (4.57 meters) to the line on their left and touched the line with their left hand, turned and sprinted 10 yards (9.14 meters) to the line on their right and touched the line with their right hand, and then turned and sprinted five yards (4.57 meters) to the center line. Subjects were familiarized with the test and instructed to complete one test with their best effort as practice. Subjects were complete two official timed trials. A minimum rest period of three minutes was allotted between each trial. The best time of completion of the two trials was analyzed.

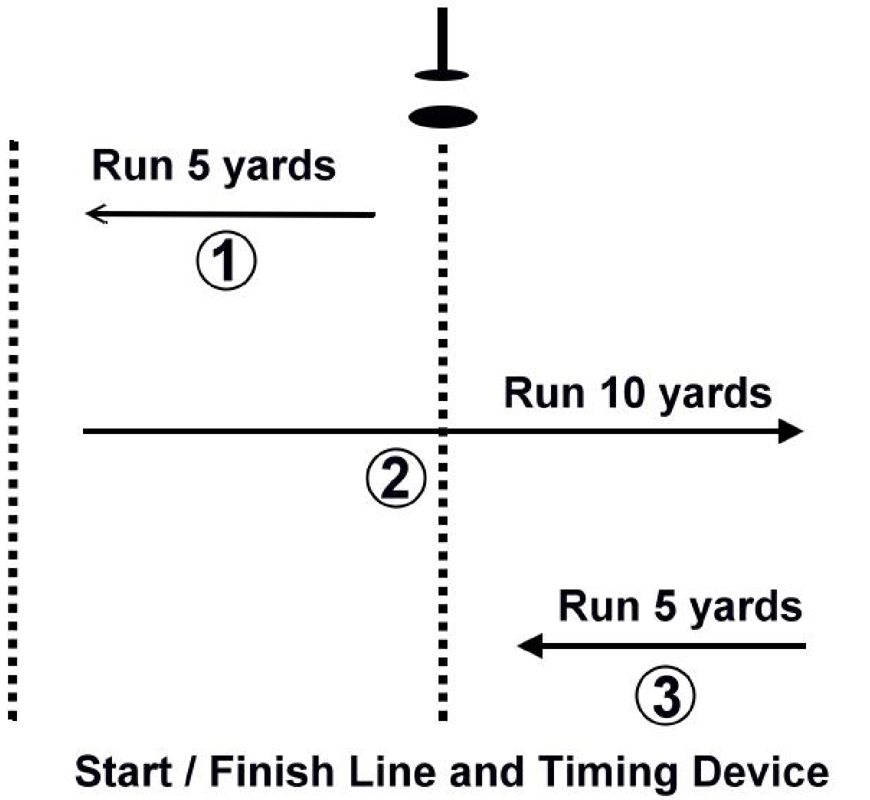


Figure 13. Agility Assessment

3.6.7 Dynamic Postural Stability Assessment

Subjects were tested on a single-leg anterior-posterior (Figure 14) jump-landing test. Subjects were positioned 40% of their body height away from the edge of a force plate. A 30 cm hurdle was stand at the midpoint of this distance. Subjects were instructed to jump, taking off of two feet, over the 30-cm hurdle, and land on the force plate on one leg. Subjects were instructed to land on the dominant leg only, stabilize as quickly as possible, place their hands on their hips, and balance for 10 seconds while looking straight ahead.

Three successful trials were collected and averaged for analyses. Subjects were given three practice trials with a one-minute rest period between practice trials and test trials. The one-minute rest period was provided between test trials to prevent fatigue. Trials were discarded and repeated if subjects failed to jump over or come in contact with the hurdle or hopped on the test leg after landing, their non-weight-bearing leg touched down off of the force place, or if they removed their hands from their hips for longer than five seconds. Trials were not discarded if subjects touched down with the non-weight-bearing leg as long as the touchdown occurred on the force plate and they resumed the one-legged stance as quickly as possible, and none of the aforementioned trial exclusion criteria occurred. The specific variable to be analyzed was the dynamic postural stability index in the anterior-posterior direction (DPSI-AP).

Figure 14. Dynamic Postural Stability in the Anterior-posterior Direction

3.6.8 Isokinetic Knee Muscular Strength Assessment

For knee muscular strength testing, subjects sat in a comfortable upright position on the Biodex dynamometer chair and were secured using thigh, pelvic, and torso straps to minimize extraneous body movements and momentum (Figure 15). The lateral femoral epicondyle was used as the bony landmark for aligning the axis of rotation of the knee joint with the axis of rotation of the dynamometer. During testing, subjects were asked to hold the chair handles with their hands. Subjects were asked to perform five knee flexion and extension isokinetic contractions on their dominant limb at 60°/sec. Three practice trials at 50 percent effort and three practice trials at maximal effort preceded actual testing to ensure free movement, proper warm-up, and comfort of the subject throughout the range of motion. Only the average peak torque produced by dominant knee extension normalized by body mass was analyzed.

Figure 15. Isokinetic Knee Muscular Strength Assessment

3.6.9 Isokinetic Shoulder Muscular Endurance Assessment

For shoulder rotation muscular endurance testing, subjects sat in a comfortable upright position on the Biodex dynamometer chair and were secured using pelvic and torso straps in order to minimize extraneous body movements and momentum (Figure 16). The subjects' shoulders were placed at approximately 15° of abduction and 15° of flexion. Subjects were asked to perform 25 shoulder internal and external isokinetic contractions at 180°/sec on their dominant limb. Three practice trials at 50 percent effort and three practice trials at maximal effort preceded actual testing to ensure free movement, proper warm-up, and comfort of the subject throughout the range of motion. Only the total work performed by dominant shoulder external rotation normalized by body mass was analyzed.

Figure 16. Isokinetic Shoulder Muscular Endurance Assessment

3.6.10 Anaerobic Capacity Assessment

The test was performed using an electronically braked bicycle ergometer (Figure 17). After a five-minute warm-up at 125 watts, the subject pedaled at 100 rpm for 15 seconds, and then pedaled as fast as possible within five seconds. By the end of the five-second ramp-up, a fixed resistance was applied to the flywheel and the subject continued to pedal "all out" for 30 seconds. Flywheel resistance equaled 0.090 kg per kg body mass. An electrical counter continuously recorded flywheel revolutions in five-second intervals. The specific variable to be analyzed was the normalized anaerobic capacity. Anaerobic capacity is the average of the power output during the 30-second test. Anaerobic capacity was normalized by body mass.

Figure 17. Anaerobic Capacity Assessment

3.6.11 Aerobic Capacity Assessment

The test was performed using a treadmill controlled by the Parvomedics metabolic unit (Figure 18). Subject first sat down for five minutes, and a baseline lactate measurement was taken by the end of the rest period. If the lactate level was greater than 3.0 mmol/L, another five-minute rest and measurement period were given. Subject were asked to wear a heart rate monitor and a breathing mask. Subject were instructed to warm up on the treadmill at 75 percent of their two-mile run pace for five minutes. A lactate measurement was taken during the last 30 seconds of the warm-up. The modified Astrand protocol utilized in this test consisted of three-minute stages, and the treadmill incline started at zero and increased two percent by the end of each stage. Subjects were instructed to run at 85 percent of their two-mile run pace during the protocol. During each stage, subjects were notified of their progress when they were halfway through the stage, one minute before the end of the stage, and near the end of the stage. Subjects were also be asked if they can continue when they were halfway through and near the end of each stage. Lactate measurements were taken during the final 30 seconds of each stage. Subjects were encouraged to continue running until volitional fatigue. After test termination, subjects were asked to walk at 2.5 miles per hour for three minutes for active recovery. The specific variable to be analyzed was the maximal oxygen uptake.

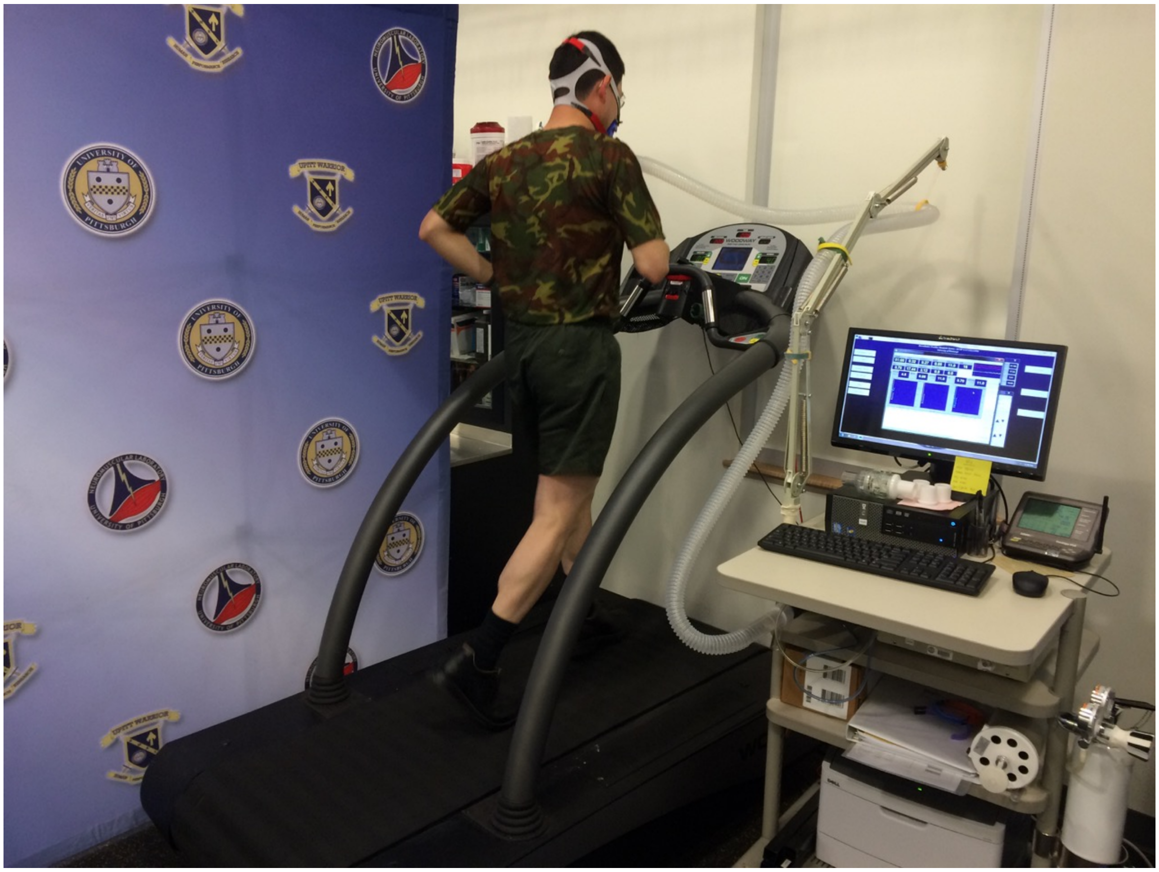


Figure 18. Aerobic Capacity Assessment

3.7 DATA REDUCTION

3.7.1 Body Composition Assessment

The BOD POD Body Composition Tracking System Version 5.2 (Life Measurement Instruments, Concord, CA) provided body fat percentage (%) data. The BOD POD system first produced the body weight and body volume, which were converted to body density as shown in Figure 19. The body density was then be input into the Siri[99] and Schutte[100] formulas to produce body fat percentage as shown in Figure 20 and 21. In addition, fat free mass was calculated using the formula shown in Figure 22.

$$\boxed{\text{Body Density} = \text{Body Weight} / \text{Body Volume}}$$

Figure 19. Body Density Formula

$$\boxed{\text{Body Fat Percentage} = (4.95 / \text{Body Density} - 4.50) * 100}$$

Figure 20. Siri Body Fat Percentage Formula

$$\boxed{\text{Body Fat Percentage} = (4.374 / \text{Body Density} - 3.928) * 100}$$

Figure 21. Schutte Body Fat Percentage Formula

$$\boxed{\text{Fat Free Mass} = \text{Body Mass} * (1 - \text{Body Fat Percentage})}$$

Figure 22. Fat Free Mass Formula

3.7.2 Flexibility Assessment

Subjects performed three successful trials with the sit-and-reach box. Trials were considered successful if the subjects kept their hands parallel and knees at full extension during the forward reach. The best of the three trials was recorded.

3.7.3 Agility Assessment

Subjects performed two successful Pro Agility tests. Trials were considered successful if the subjects touched the left and right lines with their hands. The best of the two trials was recorded.

3.7.4 Dynamic Postural Stability Assessment

A custom program in Matlab Version 7.12 Release 2011 (The MathWorks, Inc., Natick, MA, U.S.A.), was used for the calculation of dynamic postural stability variables. For dynamic postural stability, force plate data were filtered using a low-pass, zero-lag fourth-order Butterworth filter at a cutoff frequency of 20 Hz.[65] The dynamic postural stability index in the anterior-posterior direction was computed using the first three seconds of the ground reaction forces following initial contact with the formula shown in Figure 23.[65] The threshold for determining initial contact with the force plate was 5% of the subject's body mass. A total of three trials were averaged and used for analysis.

$$\boxed{\text{DPSI} = \left(\sqrt{\frac{\Sigma(0\text{-GRFx})^2 + \Sigma(0\text{-GRFy})^2 + \Sigma(\text{body weight-GRFz})^2}{\text{number of data points}}} \right) \div \text{body weight}}$$

Figure 23. Calculation for the Dynamic Postural Stability Index (DPSI)

3.7.5 Isokinetic Knee Muscular Strength Assessment

The Biodex Advantage Software Version 3.4 (Biodex Medical Systems, Inc., Shirley, NY) provided average peak torque data (Newton-meter) for the isokinetic knee muscular strength measurement. The average peak torque was normalized by subjects' body mass for further analysis.

3.7.6 Isokinetic Shoulder Muscular Endurance Assessment

The Biodex Advantage Software Version 3.4 (Biodex Medical Systems, Inc., Shirley, NY) provided total work data (Joules) for the isokinetic shoulder muscular endurance measurement. The total work was calculated from the raw torque and position data from the Biodex system, using the formula as shown in Figure 24. The total work was normalized by subjects' body mass for further analysis.

$$\boxed{\text{Work} = \text{Torque} * 2\pi * \text{Angle Change}}$$

Figure 24. Total Work Formula

3.7.7 Anaerobic Capacity Assessment

The Velotron Wingate Version 1.0.1(RacerMate, Inc., Seattle, WA) provided anaerobic capacity data, which were normalized by subjects' body mass (watts/kg). The anaerobic capacity is the average power output throughout the 30-second Wingate protocol.

3.7.8 Aerobic Capacity Assessment

The ParvoMedics TrueOne Metabolic System OUSW 4.3.4 (ParvoMedics, Sandy, UT) provided the metabolic data. The test was considered successful if the at least two of the following criteria were met after test termination: 1) post-test lactate level was equal to or greater than 8 mmol/L, 2) respiratory exchange ratio was greater than 1.08, 3) heart rate was within 10 beats per minute of age-predicted maximum (220 – age), 4) a plateau was shown with increasing intensity.

3.8 STATISTICAL ANALYSIS

Data were analyzed using STATA 12 (StataCorp LP, College Station, TX). Descriptive statistics were calculated for all variables. Data were tested for assumptions of normality of data and multi-collinearity of the independent variables. Simple linear regression models were utilized to screen for and select potentially important independent variables to be included in the final model.

Backward stepwise multiple linear regression method was then used to further test for candidate independent variables and eliminate those with no significant effect. A candidate multiple linear regression model was fit using the remaining independent variables. The final multiple regression model was presented and interpreted after performing model diagnostics. Statistical significance for tests was set *a priori* as $\alpha = 0.05$.

4.0 RESULTS

The results section begins with description of the characteristics of the enrolled subjects. Due to lack of response to recruitment from military population, enrollment was opened to civilian with permission from the dissertation committee and the university institutional review board. Additional analyses were conducted to ensure the military and civilian groups were similar in subject characteristics as well as independent and dependent variables. Next, summary of independent and dependent variables as well as their normality is depicted. Furthermore, the relationships between independent and dependent variables are examined through the use of two-way scatter plots, Pearson's correlation coefficients, and simple linear regression analyses. Lastly, the identification of the predictive independent variables is made through the use of backward stepwise multiple linear regression analysis.

4.1 SUBJECT CHARACTERISTICS

Twenty-nine subjects with military experience were enrolled in this study. Twenty-eight subjects with military experience completed both laboratory and field test sessions. One subject did not return for the laboratory test session and thus his data were excluded from analyses. Of the 28 subjects: 22 were ROTC cadets who only had military experience through their program, one was an ROTC cadet who was also a discharged Army Soldier, one was an Army National Guard, one was an Air Force Reservist, one was a discharged Army Soldier, and two were discharged Marine Soldiers.

Due to lack of response to recruitment, the inclusion criteria of having military experience was removed with permission from the dissertation committee and the university institutional review board, and any persons meeting the remaining inclusion and exclusion criteria could participate in the study. An additional 15 subjects without military experience were enrolled in this study, and they all completed the laboratory and field test sessions. The total number of subjects enrolled in this study was 43. Subject characteristics data for subjects with and without military experience, as well as the overall sample are shown in Table 16.

Table 16. Subject Characteristics

		n	Mean	±	SD	Median	Interquartile Range (25th	,	75th)	Range (Min	,	Max)
Age (yrs)	Military	28	21.07	±	2.80	20.50	19.50	,	21.00	18.00	,	30.00
	Civilian	15	22.20	±	3.00	21.00	20.00	,	23.00	19.00	,	30.00
	All	43	21.47	±	2.89	21.00	20.00	,	22.00	18.00	,	30.00
Height (cm)	Military	28	177.08	±	7.36	176.91	172.28	,	182.00	160.10	,	194.15
	Civilian	15	179.47	±	8.32	182.70	172.90	,	185.00	165.78	,	194.70
	All	43	177.91	±	7.70	177.32	172.30	,	183.90	160.10	,	194.70
Mass (kg)	Military	28	77.05	±	9.53	76.45	69.88	,	81.31	63.64	,	106.73
	Civilian	15	79.28	±	13.77	73.48	69.82	,	85.64	64.67	,	116.11
	All	43	77.82	±	11.08	76.33	69.83	,	81.74	63.64	,	116.11
Military Experience (yrs)	Military	28	3.11	±	2.48	3.00	1.00	,	12.00	1.00	,	12.00

In order to determine whether or not subjects with and without military experience can be analyzed as one group, independent sample t-tests or Mann-Whitney U tests were performed to compare subjects with or without military experience on age, height, and body mass, as well as independent and dependent variables which will be presented in Section 4.2. Shapiro-Wilk test of normality indicated height was normally distributed (p = 0.848; p = 0.716), but not age (p < 0.001; p = 0.007) or body mass (p = 0.037; p = 0.008). For height, Levene's test indicated equal variances could be assumed (p = 0.306), and independent sample t-test showed there were no significant differences between subjects with or without military experience (p = 0.338). Mann-Whitney U tests indicated there were no significant differences between subjects with or without military experience on age (p = 0.113) or body mass (p = 0.799). Based on comparisons on age, height, and body mass, subjects could be combined as one group for further analyses. But further comparisons on independent and dependent variables are needed, which will be presented in Section 4.2.

4.2 INDEPENDENT AND DEPENDENT VARIABLES - SUMMARY DATA AND NORMALITY TEST RESULTS

Summary data for all variables and groups are presented in Table 17. In order to determine whether or not subjects with and without military experience can be analyzed as one group, independent sample t-tests or Mann-Whitney U tests were performed to compare subjects with or without military experience on independent and dependent variables, including muscular strength and endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, agility, and time to completion of the proposed Army Combat Readiness Test. Shapiro-Wilk test of normality indicated muscular strength and endurance, postural stability, anaerobic capacity, flexibility, body composition, agility, and time to completion of the proposed Army Combat Readiness Test were normally distributed ($p > 0.05$; $p > 0.05$), but not aerobic capacity ($p = 0.003$; $p = 0.164$) or fat-free mass ($p = 0.043$; $p = 0.072$). Levene's test indicated equal variances could be assumed for muscular strength and endurance, postural stability, anaerobic capacity, flexibility, agility, and time to completion of the proposed Army Combat Readiness Test ($p > 0.05$), but not body composition ($p = 0.011$). Independent sample t-tests showed there were no significant differences between subjects with or without military experience on muscular strength and endurance, postural stability, anaerobic capacity, flexibility, body composition, agility, and time to completion of the proposed Army Combat Readiness Test ($p > 0.05$). Mann-Whitney U tests indicated there were no significant differences between subjects with or without military experience on aerobic capacity ($p = 0.721$) or fat-free mass ($p = 0.878$). Based on comparisons on age, height, and body mass from Section 4.1, as well as the independent and dependent variables, subjects were combined as one group for further analyses.

Normality of the independent and dependent variables of the combined group sample was assessed using Shapiro-Wilk tests ($p < 0.05$). The independent variables, muscular strength and endurance, anaerobic capacity, flexibility, and agility were normally distributed ($p = 0.717$; $p = 0.832$; $p = 0.444$; $p = 0.461$; $p = 0.911$), but not postural stability, aerobic capacity, body composition, and fat-free mass ($p = 0.027$; $p = 0.015$; $p =0.001$; $p = 0.013$). The dependent variable, time to completion of the proposed Army Combat Readiness Test, was normally distributed ($p = 0.967$).

Table 17. Dependent and Independent Variable Summary Data

							Interquartile Range			Range		
		n	Mean	±	SD	Median	(25th	,	75th)	(Min	,	Max)
ACRT (seconds)	Military	28	240.84	±	28.77	242.99	224.97	,	258.74	187.97	,	293.65
	Civilian	15	234.36	±	35.72	233.27	207.31	,	261.66	172.12	,	308.43
	Total	43	238.58	±	31.10	235.17	220.01	,	259.76	172.12	,	308.43
Muscular Strength (Nm/kg)	Military	28	269.08	±	37.94	269.69	242.59	,	309.73	185.26	,	321.70
	Civilian	15	293.83	±	48.68	285.90	250.39	,	330.70	233.03	,	376.84
	Total	43	277.71	±	43.10	273.16	246.02	,	313.37	185.26	,	376.84
Muscular Endurance (J/kg)	Military	28	910.44	±	213.02	871.81	802.37	,	1048.36	437.33	,	1353.10
	Civilian	15	962.86	±	228.07	897.11	780.96	,	1102.39	677.89	,	1499.82
	Total	43	928.73	±	217.14	875.95	784.70	,	1096.10	437.33	,	1499.82
Postural Stability	Military	28	0.38	±	0.04	0.37	0.34	,	0.39	0.31	,	0.48
	Civilian	15	0.37	±	0.03	0.37	0.36	,	0.39	0.33	,	0.44
	Total	43	0.38	±	0.04	0.37	0.34	,	0.39	0.31	,	0.48
Aerobic Capacity (mL/kg/min)	Military	28	55.74	±	9.61	54.82	48.61	,	59.33	43.39	,	86.11
	Civilian	15	53.74	±	8.95	55.47	52.08	,	57.60	35.49	,	69.27
	Total	43	55.04	±	9.32	54.91	49.37	,	58.74	35.49	,	86.11
Anaerobic Capacity (watts/kg)	Military	28	8.88	±	1.25	8.87	8.18	,	9.77	5.64	,	11.56
	Civilian	15	8.73	±	1.73	9.25	7.51	,	10.05	5.65	,	11.69
	Total	43	8.82	±	1.42	9.05	7.69	,	9.77	5.64	,	11.69
Flexibility (cm)	Military	28	29.58	±	7.95	29.70	25.75	,	36.05	14.80	,	45.80
	Civilian	15	27.55	±	6.32	28.50	24.20	,	32.20	13.00	,	37.00
	Total	43	28.87	±	7.41	29.20	25.20	,	33.80	13.00	,	45.80
Body Composition (%)	Military	28	13.74	±	4.42	12.75	10.40	,	16.50	5.30	,	24.00
	Civilian	15	15.83	±	8.63	13.50	9.80	,	20.20	5.40	,	37.50
	Total	43	14.47	±	6.20	13.30	10.20	,	17.60	5.30	,	37.50
Fat-free Mass (kg)	Military	28	66.39	±	8.05	65.25	61.01	,	70.94	50.64	,	91.61
	Civilian	15	67.68	±	9.18	63.27	61.72	,	74.06	55.75	,	85.62
	Total	43	66.84	±	8.37	65.03	61.42	,	71.17	50.64	,	91.61
Agility (seconds)	Military	28	5.15	±	0.31	5.14	4.95	,	5.31	4.43	,	6.02
	Civilian	15	5.04	±	0.37	5.02	4.70	,	5.40	4.35	,	5.64
	Total	43	5.11	±	0.34	5.09	4.92	,	5.37	4.35	,	6.02

ACRT = Time to Completion of the Proposed Combat Readiness Test
Muscular Strength = Average Peak Torque Normalized by Body Mass
Muscular Endurance = Total Work Normalized by Body Mass
Aerobic Capacity = Maximal Oxygen Uptake Normalized by Body Mass
Flexibility = Sit-and-reach Distance
Body Composition = Percent body fat
Fat-free Mass = Mass of Fat-free Tissues
Agility = Time to Completion of the Pro-agility Test

4.3 THE RELATIONSHIPS BETWEEN INDEPENDENT AND DEPENDENT VARIABLES: TWO-WAY SCATTER PLOTS AND PEARSON'S CORRELATION COEFFICIENTS

Two-way scatter plots for the dependent and independent variables are presented in Appendix C. Positive linear trends were revealed in time to completion of the proposed ACRT and postural stability, body composition, and agility. Negative linear trends were revealed in time to completion of the proposed ACRT and muscular strength and endurance, aerobic capacity, anaerobic capacity, flexibility, and fat-free mass.

Pearson's correlation coefficients were calculated for each pair of dependent and independent variables (Table 18). Pearson's correlation coefficients were significant between time to completion of the proposed ACRT and muscular endurance, aerobic capacity, anaerobic capacity, and body composition respectively ($p < 0.05$). There were also some coefficients between independent variables that were statistically significant, but they were all less than 0.80, which gave initial indications that there were no collinearity problems with the multiple linear regression model.

Table 18. Pearson's Correlation Coefficient Matrix for Independent and Dependent Variables

	ACRT	Strength	ME	DPSI	VO2max	AVGP	Flex	Bodyfat	Fatfree	Agility
Strength	-0.15 (0.346)	1.00								
ME	-0.35 (0.021)	0.24 (0.128)	1.00							
DPSI	0.13 (0.419)	-0.05 (0.759)	0.00 (0.996)	1.00						
VO2max	-0.58 (<0.001)	-0.01 (0.945)	0.26 (0.094)	-0.01 (0.953)	1.00					
AVGP	-0.59 (<0.001)	0.30 (0.049)	0.43 (0.004)	-0.18 (0.241)	0.67 (<0.001)	1.00				
Flex	-0.23 (0.130)	0.16 (0.312)	0.03 (0.852)	-0.03 (0.840)	0.35 (0.022)	0.41 (0.007)	1.00			
Bodyfat	0.53 (<0.001)	-0.11 (0.467)	-0.20 (0.190)	0.10 (0.523)	-0.59 (<0.001)	-0.65 (<0.001)	-0.30 (0.048)	1.00		
Fatfree	-0.15 (0.328)	0.12 (0.460)	0.02 (0.887)	-0.23 (0.147)	-0.10 (0.509)	0.00 (0.991)	-0.31 (0.045)	-0.08 (0.632)	1.00	
Agility	0.42 (0.005)	-0.45 (0.003)	-0.19 (0.211)	0.10 (0.527)	-0.25 (0.109)	-0.52 (<0.001)	-0.29 (0.060)	0.31 (0.041)	0.11 (0.479)	1.00

p-values are in parentheses
ACRT = time to completion of the proposed ACRT (seconds)
Strength = average peak torque of knee extension normalized by body mass (Nm/kg)
ME = total work of shoulder external rotation normalized by body mass (J/kg)
DPSI = dynamic postural stability index during a two-legged jump and one-legged landing task
VO2max = maximum oxygen uptake normalized by body mass (mL/kg/min)
AVGP = average peak power normalized by body mass during a 30-second Wingate protocol (watts/kg)
Flex = sit-and-reach distance (cm)
Bodyfat = percent body fat during a BOD POD assessment (%)
Fatfree = the mass of fat-free tissues calculated using percent body fat
Agility = time to completion of the Pro Agility test

4.4 THE RELATIONSHIPS BETWEEN INDEPENDENT AND DEPENDENT VARIABLES: SIMPLE LINEAR REGRESSION MODELS

Simple linear regression analyses, with the aim of aiding multiple linear regression analyses, were performed in order to understand whether time to completion of the proposed ACRT can be predicted individually based on muscular strength and endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility. Findings are presented in Table 19. Jackknife residuals of each independent variable were then plotted against the predicted values of time to completion of the proposed ACRT to assess whether or not the assumption of linearity, homoscedasticity, and outliers were met (Appendix D). Visual inspection of the jackknife vs. predicted values plots confirmed the assumptions of linearity and homoscedasticity, and no obvious outliers were observed. Outliers were defined as having studentized residuals greater or less than 3.0. Homogeneity of variance was further confirmed with non-significant ($p > 0.05$) Breush-Pagan tests for heteroscedasticity of all models.

Simple linear regression analyses showed that the time to completion of the proposed ACRT could be significantly predicted by muscular endurance, aerobic capacity, anaerobic capacity, body composition, and agility. Muscular endurance, aerobic capacity, anaerobic capacity, body composition, and agility accounted for 12.34, 34.01, 34.28, 28.14, and 17.58 percent of the variance in time to completion of the proposed ACRT respectively.

Table 19 Simple Linear Regression Model to Predict Time to Completion of the Proposed Combat Readiness Test

Predictor Variable	Model MSE	R^2	Model p Value
Average peak torque normalized by body mass (Nm/kg)	31.14	0.02	0.35
Total work normalized by body mass (J/kg)	29.47	0.12	0.02
Dynamic postural stability index	31.23	0.02	0.42
Maximal oxygen uptake normalized by body mass (mL/kg/min)	25.57	0.34	< 0.01
Average peak power normalized by body mass (watts/kg)	25.52	0.34	< 0.01
Sit-and-reach distance (cm)	30.60	0.06	0.13
Percent body fat (%)	26..69	0.28	< 0.01
Mass of fat-free tissues (kg)	31.11	0.02	0.33
Time to completion of the Pro-agility Test (seconds)	28.58	0.18	0.01

4.5 THE IDENTIFICATION OF THE PREDICTIVE INDEPENDENT VARIABLES: MULTIPLE LINEAR REGRESSION MODELS

Backward stepwise multiple linear regression analysis was performed for the time to completion of the proposed combat readiness test with muscular strength, muscular endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility. The final multiple linear regression model demonstrated that muscular endurance, aerobic capacity, body composition, fat-free mass, and agility, statistically significantly predict the time to completion of the proposed combat readiness test ($F(5, 37) = 7.95$, $p < 0.001$). Muscular endurance, aerobic capacity, body composition, fat-free mass, and agility taken together were responsible for 51.78 percent of the explained variability in the time to completion of the proposed combat readiness test. The summary of the final multiple linear regression model is presented in Table 20. Jackknife residuals were then plotted against the predicted values of time to completion of the proposed ACRT to assess whether or not the assumption of linearity, homoscedasticity, and outliers were met (Figure 25). Visual inspection of the jackknife vs. predicted values plots confirmed the assumptions of linearity and homoscedasticity, and no obvious outliers were observed. Outliers were defined as having studentized residuals greater or less than 3.0. Homogeneity of variance was further confirmed with non-significant ($p > 0.05$) Breush-Pagan test for heteroscedasticity of the model. Normality of the distribution of the residuals was assessed using Shapiro-Wilk tests ($p < 0.05$), which were shown to be normally distributed ($p = 0.644$). The Variance Inflation Factors (VIF) were calculated for each predictor variables and there were no evidence of collinearity problems (VIF < 10). Potential high leverage points were assessed using Hadi's Influence (*Hi*), which indicated potential problems with four subjects. Potential influential points were assessed using Cook's Distance (Cook's *Di*), which also indicated potential problems with four subjects.

The fitted multiple linear regression equation was: time to completion of the proposed ACRT = 250.21 – 0.02 * muscular endurance – 1.34 * aerobic capacity + 0.81 * body composition – 0.77 * fat-free mass + 24.12 * agility. In the fitted multiple linear regression equation, aerobic capacity and agility were significant predictors of the time to completion of the proposed combat readiness test. Other predictors being kept constant, the time to completion of the proposed combat readiness test decreased by 1.34 seconds for every unit increase in the aerobic capacity (maximal oxygen uptake normalized by body mass (mL/kg/min)). Other predictors being kept constant, the time to completion of the proposed combat readiness test increased by 24.12 seconds for every unit increase in the agility (time to completion of the Pro-agility test (seconds)).

Table 20. Multiple Regression Model to Predict Time to Completion of the Proposed Combat Readiness Test

Coefficients				
Predictor Variables	Coefficient	Standardized Coefficient	t	p-value
Total Work Normalized by Body Mass (J/kg)	-0.023	-0.159	-1.33	0.193
Maximal Oxygen Uptake Normalized by Body Mass (mL/kg/min)	-1.344	-0.403	-2.75	0.009
Body Composition (percent of body fat)	0.813	0.162	1.10	0.281
Mass of Fat-free Tissues (kg)	-0.772	-0.208	-1.77	0.085
Time to Completion of the Pro-agility Test (seconds)	24.124	0.261	2.12	0.041
Constant	250.208	0.000	3.38	0.002

Model Summary			
Observation	F (5,37)	Prob >F	R^2
43	7.95	<0.001	0.5178

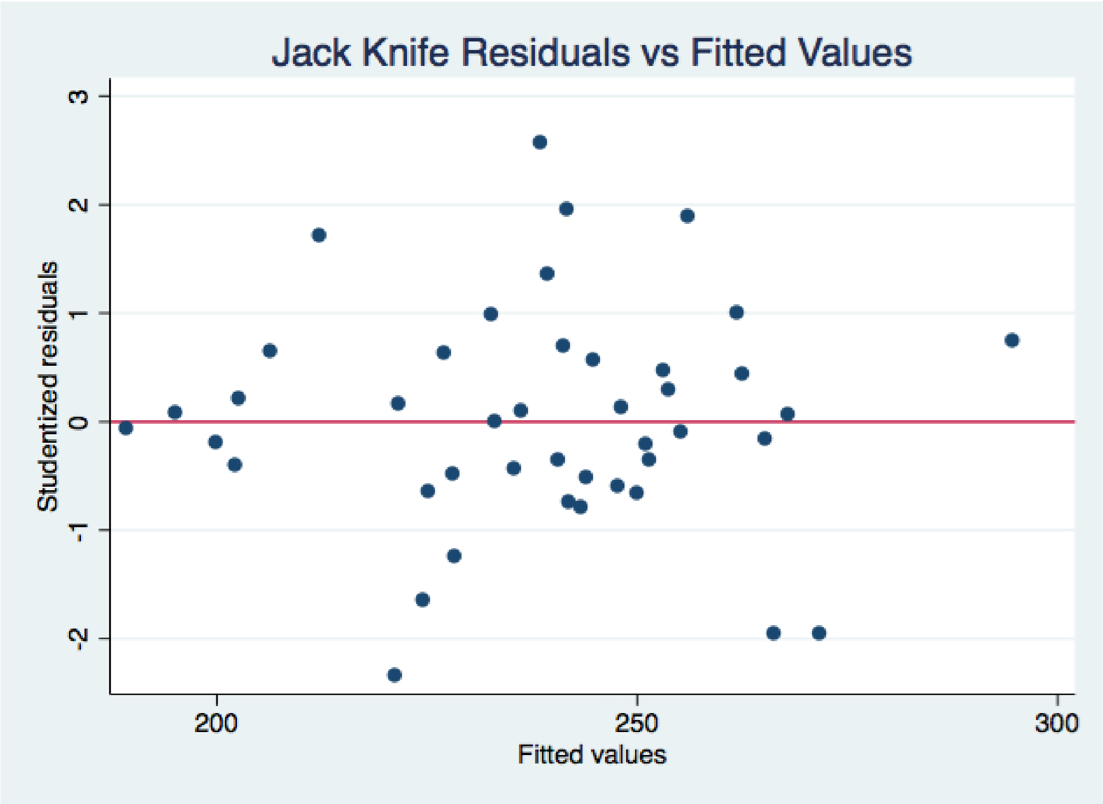


Figure 25. Multiple Linear Regression Fitted Values vs. Jackknife Residual Plot for Time to Completion of the Proposed Combat Readiness Test (seconds)

5.0 DISCUSSION

The purpose of this study was to identify the underlying and modifiable physical fitness components of a proposed combat readiness test. It was hypothesized that a strong and significant multiple linear regression model can be built to predict time to completion of the proposed Army Combat Readiness Test, using muscular strength, muscular endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility as predictors. The hypothesis was partially supported because only muscular endurance, aerobic capacity, body composition, fat-free mass, and agility were selected in the final multiple linear regression model.

The discussion section will begin with examination of subject characteristics. Next, dependent and independent variables will be compared to previous research individually and as pairs, and their similarities or deviations will be discussed. The same process will be applied to discussion on the multiple regression model built based on them. Lastly, the study limitations, significance, future study directions, and conclusions will be presented.

5.1 SUBJECT CHARACTERISTICS

Due to lack of lack of response to recruitment by subjects with military experience, civilians were allowed to participate in this study. Comparisons of demographics, independent and dependent variables between two groups did not reveal any significant differences. However, only 6 out of 28 subjects with military experience have served in the military. The rest only have military experience from ROTC programs. It is possible that this is the reason why there are no significant differences in independent and dependent variables between subjects with and without military experience.

5.2 DEPENDENT VARIABLE - THE PROPOSED ARMY COMBAT READINESS TEST

The average time to completion of the proposed ACRT was 238.58 ± 31.10 seconds, which was considerably faster than 286.55 ± 27.39 seconds reported by Hasselquist.[101] Given that the run distance for the *400-Meter Run* in this study was shortened to 281.64 meters due to logistic difficulties, the faster time reported in this study is expected. In addition, the 9-event proposed ACRT in this study requires longer completion time than Harman's[6] 8-event obstacle course (68.2 ± 12.3 seconds) and Bishop's[28] 11-event obstacle course (186.7 ± 68.6 seconds), but shorter than Jette's[29] 19-event obstacle course (317 ± 51 seconds). Despite the seemingly small number of events in the proposed ACRT, it took longer to complete the course as compared to Harman's[6] and Bishop's[28]. This may be explained by the longer running distance and material handling events in the proposed ACRT. The total distances of the obstacle courses in Harman's[6] and Bishop's[28] studies were 63.4 and 330.2 meters respectively, as opposed to 455.38 meters in this study. In addition, there were no material handling events in the obstacle course in Harman's[6] study, while subjects were required to carry a 4.2-kg medicine ball for 137 meters in Bishop's[28] study. In comparison, subjects in this study were instructed to drag an 81.6-kg casualty rescue sled for 18.29

meters, carry a 13.6-kg ammunition can in each hand while negotiating balance beams for a total of 10.8 meters, and perform a 91.44-meter shuttle run while carrying a 13.6-kg ammunition can in each hand. On the other hand, the total distance of the obstacle course in Jette's[29] study was 580 meters, and there were numerous lifting and carrying events in it, such as *5-meter rope pull*, *40-meter ammo box lift and carry*, *16-meter tire pull*, and *60-meter sandbag lift and carry*.

5.3 INDEPENDENT VARIABLES - PHYSICAL FITNESS COMPONENTS

5.3.1 Muscular Strength

The average peak torque produced by dominant knee extension normalized by body mass was 277.71 ± 43.10 Nm/kg. Subjects in this study demonstrated greater muscular strength compared to Army 101st male soldiers in similar age ranges of 20-24 years old (left: 229.81 ± 43.67 Nm/kg; right: 241.67 ± 48.92 Nm/kg) and 25-29 year-old (left: 228.74 ± 45.36 Nm/kg; right: 238.68 ± 49.37 Nm/kg).[102] When compared to a wider age range of 20-44 years old (left: 226.02 ± 44.56; right: 236.12 ± 48.03 Nm/kg),[75] subjects in this study still displayed higher muscular strength. Subjects in this study were also stronger than male triathletes qualified for Ironman World Championships (left: 241.31 ± 42.31; right: 242.09 ± 50.38 Nm/kg),[75] but weaker than elite male rugby players (side with 280.7 ± 70.4 Nm/kg).[103]

5.3.2 Muscular Endurance

The average work performed by dominant shoulder external rotation normalized by body mass was 928.73 ± 217.14 J/kg. To the principal investigator's knowledge, this is the first study to report isokinetic shoulder external rotation performance with this protocol in an athletic population. Therefore, it is not possible to make direct comparisons with literatures.

5.3.3 Postural Stability

The average dynamic postural stability index was 0.38 ± 0.04. Subjects in this study showed equivalent postural stability compared to Army 101st Soldiers (0.32 ± 0.04),[104] elite male rugby players (0.32 ± 0.03),[103] and physically active college students (0.35 ± 0.04).[65]

5.3.4 Aerobic Capacity

The average maximal oxygen uptake was 55.04 ± 9.32 mL/kg/min. Subjects in this study demonstrated a higher aerobic capacity compared to Army 101st male soldiers in the similar age range of 20-24 years old (48.73 ± 6.33 mL/kg/min) and 25-29 year-old (48.07 ± 7.22 mL/kg/min).[102] When compared to a wider age range of 20-44 years old (47.5 ± 7.6 mL/kg/min),[75] subjects in this study still displayed higher aerobic capacity. In addition, their test values were higher than male ROTC cadets (49.6 ± 6.1 mL/kg/min),[105] and male Army recruits (50.6 ± 6.2 mL/kg/min),[87] but lower than male triathletes qualified for Ironman World Championships (69.8 ± 7.3 Nm/kg).[75]

5.3.5 Anaerobic Capacity

The average power normalized by body mass was 8.82 ± 1.42 watts/kg. Subjects in this study demonstrated a higher anaerobic capacity compared to Army 101st male soldiers in the similar age ranges of 20-24 years old (7.84 ± 0.93 watts/kg) and 25-29 year-old (7.97 ± 1.17 watts/kg)[102] When compared to a wider age range of 20-44 years old (7.8 ± 1.0 watts/kg),[75] subjects in this study still displayed higher anaerobic capacity. In addition, their test values were higher than male U.S. Military Academy cadets (7.5 ± 1.1 watts/kg),[28] but lower than male triathletes qualified for Ironman World Championships (9.3 ± 0.7 watts/kg).[75]

5.3.6 Flexibility

The average sit-and-reach distance was 28.87 ± 7.41 cm. Subjects in this study demonstrated equivalent flexibility compared to Army National Guard male Soldiers (28.4 ± 8.1 cm),[106] as well as Army active duty Soldiers of both genders (26.8 ± 7.3 cm).[107] In addition, their test values were considered "Fair" according to the normative standards published by American College of Sports Medicine.[72]

5.3.7 Body Composition

The average percent body fat was 14.47 ± 6.20 %. Subjects in this study showed lower percent body fat compared to Army 101st male soldiers in similar age ranges of 20-24 years old (18.79 ± 7.26 %) and 25-29 year-old (19.26 ± 7.55 %).[102] When compared to a wider age range of 20-44 years old (20.1 ± 7.5 %),[75] subjects in this study still displayed lower percent body fat. In addition, their test values were comparable to male Army ROTC cadets (14.8 ± 4.2), but higher than U.S. Military Academy male cadets (10.6 ± 3.2)[28] and male triathletes qualified for Ironman World Championships (12.3 ± 4.4 %).[75]

5.3.8 Fat-free Mass

The average fat-free mass was 66.84 ± 8.37 kg. Subjects in this study have equivalent fat-free mass compared to Army 101st male soldiers in two body fat percentage groups (≤ 18%: 66.8 ± 8.2 kg; ≥ 18%: 64.6 ± 8.0 kg).[76] In addition, subjects in this study showed higher fat-free mass compared to another group of male Army Soldiers in similar age ranges of 17-20 years old (61.7 ± 6.5 kg) and 21-27 year-old (61.5 ± 7.5 kg).[108]

5.3.9 Agility

The average time to completion was 5.11 ± 0.34 seconds. Subjects in this study demonstrated equivalent agility compared to Army active duty Soldiers (5.8 ± 0.4 and 5.7 ± 0.4 seconds),[107] In addition, their test values were ranked at bottom 10th percentile compared to men's Division 1 college football players' according to the normative standards published by National Strength and Conditioning Association.[34]

5.4 PREDICTION OF THE PROPOSED ARMY COMBAT READINESS TEST PERFORMANCE

Simple linear regression analyses showed that only muscular endurance, aerobic capacity, anaerobic capacity, body composition, and agility were significant predictors, and they accounted for 12.34, 34.01, 34.28, 28.14, and 17.58 percent of the variance in time to completion of the proposed ACRT, respectively. The physical fitness components were not strong predictors by themselves. Multiple linear regression analyses produced a model that included muscular endurance, aerobic capacity, body composition, fat-free mass, and agility. The model explained 51.78 % of the variance in time to completion of the proposed ACRT and was significant; therefore, the original hypothesis was partially supported. The r^2 value is similar to the model reported by Bishop et al.[28](r^2 = 0.42), but lower than that shown by Harman et al.[6] (r^2 = 0.67) and Jette et al.[29] (r^2 = 0.81). This may be due to insufficient familiarization with the proposed ACRT by the subjects in this study, as well as the complex nature of the test. Subjects in the study of Harman et al.[6] had eight weeks of Army training before the study, which might provide them with more experience in negotiating the obstacle course. In addition, Harman's[6] obstacle course did not have material handling events and was less complicated. The majority of the subjects in the study of Jette et al.[29] were experienced Soldiers who might already possess the necessary skills to negotiate the obstacle course. In contrast, subjects in this study were mostly inexperienced ROTC cadets or civilians, who might need more practice trials to perform at their best in the proposed ACRT. Furthermore, the proposed ACRT required subjects to sling and remove a simulated rifle on their back several times during the test, which might be a fine motor task requiring more time to master.

5.4.1 Muscular Strength

Muscular strength has been considered paramount for combat readiness.[10, 26, 27, 29, 31-33, 109] Williams et al.[26] reported that static lift strength was one of the predictors of time to completion of a 3.2-km loaded march with a backpack load of 15 kg. Rayson et al.[27] reported that static strength tests of upright pull, hand grip, and back extension, as well as dynamic strength test using Incremental Lift Machine were strong predictors of several lifting or carrying tasks. Similarly, maximal lifting performance could be predicted by static upright pull[35] and incremental dynamic lifting performance.[109] Jette et al.[29] reported that a muscular strength index combining grip strength, shoulder press and leg press was one of the predictors of time to completion of 19-station obstacle course. Hogan et al.[31] reported that pull and lift strength correlated to explosive ordnance disposal training completion. Daniels et al.[33] reported that incremental dynamic lifting performance had moderate correlations with military field exercise performance, which was supported by Knapik et al. in a similar study.[32]

The proposed ACRT designer suggested that muscular strength is an important physical fitness component for good performance in the test,[10] but it was not selected as a predictor in the multiple regression model in this study. This may be due to its relatively small contributions to overall performance (Table 13). Muscular strength is only emphasized in two out of nine events in the proposed ACRT, and has the least amount of weight compared to muscular endurance, postural stability, anaerobic power, and agility.[10] On the other hand, the lack of presence of muscular strength in the multiple regression model may be due to its testing method in this study. It is possible that muscular strength can be a predictor if multiple isokinetic strength measurements on shoulder, torso, and knee were combined and used as an index.[29]

5.4.2 Muscular Endurance

Muscular endurance has been regarded as a key factor for combat readiness.[6, 10, 27, 31] Rayson et al.[27] reported that static arm flexion endurance was one of the predictors of time to completion of a 12.8-km loaded march with a backpack load of 15 and 25 kg. In the same study, static and dynamic arm endurance tests were strong predictors of carry and repetitive lift and carry tasks. In addition, Harman et al.[6] reported that number of push-ups was one of the predictors of time to completion of a casualty rescue task. In the same study, number of sit-ups was a strong predictor of time to completion of a seven-station obstacle course. Hogan et al.[31] reported that number of sit-ups correlated to explosive ordnance disposal training completion.

The proposed ACRT designer suggested that muscular endurance is an important physical fitness component for good performance in the test,[10] which is supported by the results in this study. Muscular endurance has significant contributions to overall performance (Table 13). It is emphasized in eight out of nine events in the proposed ACRT, and has the greatest amount of weight compared to muscular strength, postural stability, anaerobic power, anaerobic capacity, and agility.[10] Muscular endurance exercises using body weight as resistance have been the principal components of the U.S. Army physical training program.[14, 39] However, the U.S. Army physical training program may not be optimized for improving muscular endurance. Abt et al.[110] demonstrated that Soldiers performed more sit-ups after an eight-week optimized physical training program compared to the U.S. Army physical training program. A well balanced program targeting key muscles for the proposed ACRT may help improve combat readiness.

5.4.3 Postural Stability

Postural stability has been deemed a leading element for combat readiness.[10, 67] Mononen et al.[67] reported that postural stability correlated to rifle shooting accuracy. The proposed ACRT designer suggested that postural stability is an important physical fitness component for good performance in the test,[10] but it was not selected as a predictor in the multiple regression model in this study. This may be due to its small contributions to overall performance (Table 13). Postural stability is only emphasized in four out of nine events in the proposed ACRT, and has little amount of weight compared to muscular endurance and agility.[10]

5.4.4 Aerobic Capacity

Aerobic capacity has been considered paramount for combat readiness.[6, 26, 27, 29, 31] Williams et al.[26] reported that aerobic capacity as measured with a multi-stage shuttle run test was one of the predictors of time to completion of a 3.2-km loaded march with a backpack load of 15 kg, which was also supported by Rayson et al.[27] for predicting time to completion of a 12.8-km loaded march with 15-kg and 25-kg rucksack. In addition, Harman et al.[6] reported that a casualty rescue task performance could be predicted with aerobic capacity as measured with a 3.2-km run. Jette et al.[29] reported that aerobic capacity was one of the predictors of time to completion of a 19-station obstacle course. Hogan et al.[31] reported that aerobic capacity as measured with a 2.4-km run correlated to explosive ordnance disposal training completion.

Aerobic capacity was not mentioned as an important physical fitness component for good performance in the proposed ACRT by its designer[10], but it was selected as a predictor in the multiple regression model in this study. This finding is similar to that of Jette et al.[29], but not

Harman et al.[6] and Bishop et al.[28] This may be explained by the average time to completion of the proposed ACRT or obstacle courses. The proposed ACRT and Jette's[29] obstacle course took on average 238.58 ± 31.10 and 317 ± 51 seconds to complete, which may require greater emphasis on oxidative energy system.[34] In comparison, Bishop's[28] obstacle course may involve both anaerobic glycolysis and oxidative energy system (186.7 ± 68.6 seconds), while Harman's[6] may demand mostly anaerobic glycolysis energy system (68.2 ± 12.3 seconds). In order to improve aerobic capacity, the U.S. Army Soldiers traditionally run long distances in groups.[111] Recent studies showed that high running mileage contributed to higher injury rates, and similar or better improvement in aerobic capacity could be achieved by decreasing running mileage and emphasizing interval runs.[110, 112]

5.4.5 Anaerobic Capacity

Anaerobic capacity has been regarded as a key factor for combat readiness.[10, 28, 29, 32] Bishop et al.[28] reported that anaerobic capacity as measured by a 30-second bicycle ergometer sprint test was one of the predictors of time to completion of 11-station obstacle course. This finding was supported by Jette et al.[29] who used a 90-second bicycle ergometer sprint test to predict time to completion of 19-station obstacle course. In addition, Knapik et al.[32] reported that anaerobic capacity as measured by a 30-second bicycle ergometer sprint test had moderate correlations with military field exercise performance.

The proposed ACRT designer suggested that anaerobic capacity is an important physical fitness component for good performance in the test.[10] Anaerobic capacity also had moderate correlation with time to completion of the proposed ACRT (r = - 0.58; $p < 0.001$), and accounted for 34.28 percent of the variance in time to completion of the proposed ACRT ($p < 0.01$). But it was not selected as a predictor in the multiple regression model in this study. This may be due to its moderate correlation with aerobic capacity (r = 0.67; p < 0.001), but the correlation coefficient was less than 0.80 and thus did not indicate collinearity problems. On the other hand, the proposed ACRT designer indicated that anaerobic capacity has relatively small contributions to overall performance (Table 13). Anaerobic capacity is only emphasized in two out of nine events in the proposed ACRT, and has the least amount of weight compared to muscular endurance, postural stability, anaerobic power, and agility.[10] Furthermore, the total time to completion of the proposed ACRT indicate it may draw upon oxidative energy system more than anaerobic glycolytic system as mention in section 5.4.4.

5.4.6 Flexibility

Flexibility has been deemed a significant element for combat readiness.[31] Hogan et al.[31] reported that dynamic flexibility correlated to explosive ordnance disposal training completion. Flexibility was not mentioned as an important physical fitness component for good performance in the proposed ACRT by its designer,[10] and it was not selected as a predictor in the multiple regression model in this study. On the other hand, it is possible the sit-and-reach test utilized in this study does not reflect the flexibility required for a good performance in the proposed ACRT. The sit-and-reach test measures only the composite flexibility of the hip and lumbar joints,[72] and may not be sufficient since the proposed ACRT involves the use of multiple joints.

5.4.7 Body Composition

Body composition has been considered paramount for combat readiness. [26-29] Williams et al.[26] reported that body composition was one of the predictors of time to completion of a 3.2-km loaded march with a backpack load of 15 kg, which was also supported by Rayson et al.[27] for predicting time to completion of a 12.8-km loaded march with 15-kg rucksack. In addition, Bishop et al.[28] reported that body composition was one of the predictors of time to completion of 11-station obstacle course. This finding was supported by Jette et al.[29] for predicting time to completion of 19-station obstacle course.

Body composition was not mentioned as an important physical fitness component for good performance in the proposed by its ACRT designer,[10] but it was selected as a predictor in the multiple regression model in this study. This finding is supported by that of Bishop et al.[28] and Jette et al.[29] The U.S. Army has recognized the importance of body composition for combat readiness and has been implementing programs to control it, but overweight/obesity remains a major issue.[113] Studies have shown that improvement of body composition may require the combination of moderate diet restriction and physical activity.[114] The U.S. Army currently has more controls on exercise prescriptions for the Soldiers, but not their diets. The U.S. Army may need to be more actively involved in Soldiers' nutritional intake.

5.4.8 Fat-free Mass

Fat-free mass has been regarded as a key factor for combat readiness.[26-29] Williams et al.[26] reported that fat-free mass was one of the predictors of time to completion of a 3.2-km loaded march with a backpack load of 15 kg. In addition, Rayson et al.[27] reported that fat-free mass was one of the predictors of several maximal lifting tasks, which was supported by Sharp et al.[35] and Teves et al.[109]

Fat-free mass was not mentioned as an important physical fitness component for good performance in the proposed ACRT by its designer,[10] but it was selected as a predictor in the multiple regression model in this study. Studies have shown that resistance training can improve fat-free mass, and can also help reduce body fat when performed in conjunction with aerobic exercises.[114]

5.4.9 Agility

Agility has been deemed a leading element for combat readiness[9, 10] The proposed ACRT designer suggested that agility is an important physical fitness component for good performance in the test,[10] which is supported by the results in this study. Agility has significant contributions to overall performance (Table 13). It is emphasized in seven out of nine events in the proposed ACRT, and has greater amount of weight compared to muscular strength, postural stability, anaerobic power, and anaerobic capacity.[10] To the principal investigator's knowledge, this study is the first to measure agility as a predictor for military task performance, as well as the first to demonstrate its importance.[6, 28, 29]The U.S. Army utilizes *300-yard Shuttle Run* as the only means for agility training, which may not be sufficient for improvement.[14] Incorporating greater training volumes, intensities, and varieties for agility as part of a comprehensive physical training program has been shown to induce greater improvement in agility than traditional U.S. Army physical training program.[110]

5.5 STUDY LIMITATIONS

There are several limitations to this study. The subjects recruited were young and physically active males between the ages of 18 and 30, which only represents a small portion of military populations. The original plan was to recruit only subjects with military experience, but it was modified to include civilians as well due to lack of participation. Although there were no significant differences between military personnel and civilians in all measurements in this study, it is possible that there are differences in other measurements not included in this study.

The proposed Army Combat Readiness Test (ACRT) was assumed to be a good measurement of combat readiness, but the principal investigator is not aware of any studies validating this. It is possible that the proposed ACRT is insufficient in assessing Soldiers' ability to carry out his or her mission successfully. In addition, the principal investigator opted to have only one three-trial session due to difficulties in logistics and subject retention. It is possible that subjects' performance may change in subsequent test sessions. If this assumption holds true, it may explain the moderate r^2 values reported in this study.

5.6 STUDY SIGNIFICANCE

The proposed ACRT was designed based on common Warrior Tasks and Battle Drills performed by Soldiers, and may provide a realistic and comprehensive assessment of a Soldier's physical readiness to complete his or her missions.[8-10] Compared to studies examining the relationship between obstacle course performance and modifiable physical fitness components,[6, 28, 29] this study also revealed that a combination of physical fitness components are essential to good performance in the proposed ACRT, including muscular endurance, aerobic capacity, body composition, fat-free mass, and agility. Assuming the proposed ACRT is a good measurement of combat readiness, U.S. Army Soldiers and their physical trainers may want to consider putting more emphasis on interventions for these physical fitness components. Unit commanders can provide guidance and resources to help facilitate the change in physical fitness training. Furthermore, this study is the first to include measurement of agility, as well as demonstrating its importance compared to similar studies.[6, 28, 29] Although agility training is represented as *300-yard Shuttle Run* in the current U.S. Army physical fitness training manual FM 7-22,[14] greater training load as well as variations of training drills may be warranted.

5.7 FUTURE RESEARCH

Future research should include greater age range for subjects in order to build a prediction model which would be applicable to the whole U.S. Army. In addition, with combat arms positions in the U.S. Army now open to women, it is crucial to understand how genders affects the proposed prediction model. The U.S. Army subject experts also suggested that speed and coordination may be important for proposed ACRT performance, which were not included in this study due to safety and accuracy concerns. Future studies can examine if these two physical fitness components have significant impact on the prediction model. Lastly, with the potential inclusion of additional predicting variables, it may be important to recruit a greater number of subjects.

5.8 CONCLUSION

The purpose of this study was to identify the underlying and modifiable components of physical fitness for the proposed ACRT performance. It was hypothesized that a strong and significant multiple linear regression model would be built for predicting time to completion of the proposed ACRT in male subjects, using muscular strength, muscular endurance, postural stability, aerobic capacity, anaerobic capacity, flexibility, body composition, fat-free mass, and agility. Multiple linear regression analysis produced a model that contained muscular endurance, aerobic capacity, body composition, fat-free mass, and agility. This model was significant and together these five variables accounted for 51.78 percent of the variance in time to completion of the proposed ACRT. The original hypothesis was only partially supported as only five out of the nine independent variables were included in the model. The proposed ACRT appears to assess a combination of physical fitness components, which can be utilized to design a targeted physical fitness training program to enhance combat readiness.

APPENDIX A

ARMY PHYSICAL FITNESS TESTS (1946–PRESENT)

A. 1946 and 1950

a. Physical Fitness Test (PFT)

i. Untimed pull-ups

Soldiers will hold the bar with palms facing away from them, and pull their bodies up until their chin is above the level of a horizontal bar. They will then lower their bodies until their elbows are completely straight. They will continue for as many repetitions as possible.

ii. Untimed squat jumps

Soldiers will squat on their right heel with fingers laced on top of their head, and then spring upward until both knees are straight and both feet clear the ground. They will reverse the position of their feet bringing their right foot in front while in the air, and then drop to a squat on the left heel. They will continue for as many repetitions as possible.

iii. Untimed push-ups

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their bodies until their chest touches the hand of a judge rested on the ground, and return to the original position. They will continue for as many repetitions as possible.

iv. Two-minute straight-leg sit-ups

Soldiers will lie on their backs with their knees straight and fingers laced behind head. They will then raise their upper body and rotate somewhat to the left, and then forward far enough to touch the right elbow to the left knee. Afterward, they will lower their body until their back touches the ground, then sit up again with their upper body rotating to the right and their left elbow touching the right knee. They will continue for as many repetitions as possible in the two-minute period.

v. Three hundred-yard outdoor or 250-yard indoor shuttle run

Soldiers will run around stakes at both ends of a 60-yard long course as fast as possible. They will continue until they complete five lengths of the course, or 300 yards. If Soldiers are performing the 250-yard indoor shuttle run, they will run around a 25-yard-long course and complete ten laps.

vi. Sixty-second squat thrusts

Soldiers will start in standing position. They will bend at their knees and hips, and squat down to place both hands on the ground. They will then thrust their feet and legs backward to a front-leaning rest position with their body straight from head to heels. They will then recover to the squatting position, and then the starting position. They will continue for as many repetitions as possible in the 60-second period.

B. 1957

a. Physical Fitness Test (PFT)

Same as 1946 and 1950 PFTs

b. Physical Achievement Test (PAT)

i. Seventy-five-yard dash

Soldiers will run forward for 75 yards as fast as possible.

ii. Triple jump

Soldiers will run down a course and hop three times, and then jump as far as they can.

iii. Five-second rope climb

Soldiers will climb up a rope as far as possible up a rpoe in five seconds.

iv. One hundred and fifty-yard man carry

Soldiers will carry another Soldier of similar build on their shoulders for 150 yards as fast as possible.

v. One-mile run

Soldiers will run a one-mile course as fast as possible.

C. 1969

a. Physical Combat Proficiency Test (PCPT)

i. 40-Yard Low Crawl

Soldiers will start in a prone position. They will crawl up and down a 20-yard course for a total of 40 yards as fast as possible while keeping either their hips, stomach, or chest on the ground at all times.

ii. Horizontal Ladder

Soldiers will grasp the first rung of a horizontal ladder with both hands, and begin forward progress by grasping the next rung and propelling their bodies forward as far as they can in the one-minute period.

iii. Dodge, Run, and Jump

Soldiers will run down a course with a six-foot wide ditch and four 42-inch wide obstacles, and return to the starting position as fast as possible. They will weave between the obstacles, and jump over the ditch.

iv. Grenade Throw or 150-Yard Man Carry

Soldiers will start in the kneeling position, and throw five dummy grenades at a target 90 feet away. They will attempt to get the dummy grenades as close to the center of the target as possible. If Soldiers perform the 150-Yard Man Carry, they will carry another Soldier of similar build on their shoulders, and carry him for 150 yards as fast as possible.

v. One-Mile Run

Soldiers will run a one-mile course as fast as possible.

b. Army Minimum Physical Fitness Test – Male (AMPFT)

i. Squat Bender or Squat Stretch

Soldiers will stand with their hands on their hips. They will bend their knees with their trunk erect, and thrust their arms forward. They will then recover to the starting position, and bend forward at their waist and touch their toes while locking their knees. Afterward, they will return to the starting position. They will continue for as many repetitions as possible until they reach the required number of repetitions (a time limit is not specified).

If Soldiers perform the Squat Stretch, they will stand straight with their hands at their sides, bend their knees, incline their trunk forward, and place their hands flat on the ground between their feet and underneath their shoulders. They will then straighten their knees while keeping their feet in place and fingers touching the ground, and bend their knees again. Afterward, they will return to the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

ii. Push-Up or the eight count Push-Up

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their bodies until their chest touches the ground, and return to the original position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

If Soldiers perform the eight-count Push-Up, they will stand with their hands at their sides, bend their knees, place their hands on the ground between their legs, and thrust their legs to the rear. They will then execute two complete push-ups, thrust their legs forward, bend their knees with arms between them, and recover to the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

iii. Sit-Up or Body Twist

Soldiers will lie on their back with their arms overhead and palms facing upward. They will sit up, thrust the arms forward and touch the toes, and return to the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

If Soldiers perform the Body Twist, they will lie on their back with their arms out to the sides and their legs raised vertical. They will lower their legs to the left, raise them to vertical, lower them to the right, and raise them to vertical again. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

iv. Legs Over or Leg Spreader

Soldiers will lie on their back, with their arms overhead and palms facing upward. They will raise their legs and swing them backwards over their head until their toes touch the ground. They will then recover to the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

If Soldiers perform the Leg Spreader, they will lie on their back, and raise their legs so their heels are 10 to 12 inches from the ground. They will spread their legs as far as possible, and recover to the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

v. Squat Thrust or Mountain Climber

Soldiers will start in a standing position. They will bend at their knees and hips, and squat down to place both hands on the ground. They will then thrust their feet and legs backward to a front-leaning rest position with their body straight from head to heels. They will then recover to a squat position, and then the starting position. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

If Soldiers perform Mountain Climber, they will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then bend their knees and bring their left foot as far forward as possible, return it to the original position, and repeat the movement with their right foot. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

vi. Stationary Run or One-Half Mile Run

Soldiers will run in place, lifting their feet 4–6 inches off the ground. At the completion of every 50 steps, they will do 10 “knee touches”. They will continue for as many repetitions as possible until reaching the required number of repetitions (a time limit is not specified).

If Soldiers perform the One-Half Mile Run, they will run a one-half mile course as fast as possible.

c. Airborne Trainee Physical Fitness Test (ATPFT)

i. Chin-Up

Soldiers will grasp a horizontal bar with their palms facing them. They will pull their body directly upward until their chinis over the bar. They will then lower their body until their elbows are completely straight. They will continue for as many repetitions as possible (a time limit is not specified).

ii. Knee Bender

Soldiers will stand with their hands on their hips, bend their knees and waist slightly forward, and thrust their arms between their legs until their extended fingers touch the ground. They will then return to the starting position. They will continue for as many repetitions as possible (a time limit is not specified).

iii. Push-Up

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their body until their chest touches the hand of a judge rested on the ground, and return to the original position. They will continue for as many repetitions as possible (a time limit is not specified).

iv. Sit-Up

Soldiers will lie on their back with their knees flexed and feet on the ground, fingers interlaced behind their head. They will bend forward at their waist and raise their upper body until their head is directly over their knees. They will then recover to the starting position. They will continue for as many repetitions as possible (a time limit is not specified).

v. One-Mile Run

Soldiers run a one-mile course as fast as possible.

D. 1973

a. Advanced Physical Fitness Test (APFT)

i. Inverted Crawl

Soldiers will lie on their back, support their bodies with both their hands and feet, and move up and down a 20-yard course for a total of 40 yards as fast as possible while keeping their hands and feet on the ground at all times.

ii. Bent-Leg Sit-Ups

Soldiers will lie on their back with their knees flexed and feet on the ground, fingers interlaced behind their head. They will bend forward at the waist and raise their upper body to vertical. They will then recover to the starting position. They will continue for as many repetitions as possible in the one-minute period.

iii. Horizontal Ladder

Soldiers will grasp the first rung of a horizontal ladder with both hands, and begin forward progress by grasping the next rung and propelling their bodies forward as far as they can in the one-minute period.

iv. Run, Dodge, and Jump

Soldiers will run down a course with a five-foot wide ditch and four 42-inch-wide obstacles, and return to the starting position as fast as possible. They will weave between the obstacles, and jump over the ditch.

v. Two-Mile Run

Soldiers will run a two-mile course as fast as possible.

b. Staff and Specialist Physical Fitness test (SSPFT)

i. Push-Ups

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their bodies until their chest touches the hand of a judge rested on the ground, and return to the original position. They will continue for as many repetitions as possible in the one-minute period.

ii. Run, Dodge, and Jump

Same as APFT

iii. Bent-Leg Sit-Ups

Same as APFT

iv. Horizontal Ladder

Same as APFT

v. One-Mile Run

Soldiers run a one-mile course as fast as possible.

c. Basic physical fitness test (BPFT)

   i. Inverted Crawl

      Same as APFT

   ii. Bent-Leg Sit-Ups

      Same as APFT

   iii. Horizontal Ladder

      Same as APFT

   iv. Run, Dodge, and Jump

      Same as APFT

   v. One-Mile Run

      Same as SSPFT

d. Inclement weather/limited facility physical fitness test (IWPFT)

   i. Push-Ups

      Same as SSPFT

   ii. Bend and Reach

      Soldiers will stand with their hands on their hips, then reach down until their fingers touch the area to the rear of their heels. They will then recover to the starting position. They will continue for as many repetitions as possible in the two-minute period.

   iii. Bent-Leg Sit-Ups

      Same as APFT

   iv. Squat Thrust

Soldiers will start in a standing position. They will bend at their knees and hips, and squat down to place both hands on the ground. They will then thrust their feet and legs backward to a front-leaning rest position with their body straight from head to heels. They will then recover to the squatting position, and then the starting position. They will continue for as many repetitions as possible in the two-minute period.

v. Eighty-meter Shuttle Run

Soldiers will run up and down a ten-meter long course as fast as possible. They will continue until they complete eight lengths of the course, or 80 m.

e. Minimum physical fitness test (MPFT)

i. Push-Ups

Same as SSPFT

ii. Run, Dodge, and Jump

Same as APFT

iii. Bent-Leg Sit-Ups

Same as APFT

iv. Squat Thrust

Same as IWPFT

v. One-Half Mile Run

Soldiers will run a one-half mile course as fast as possible.

f. Airborne trainee physical fitness qualification test (ATPFT)

i. Chin-Ups

Soldiers will grasp a horizontal bar with their palms facing them. They will pull their body directly upward until their chin is over the bar. They will then lower their body until their elbows are completely straight. They will continue for as many repetitions as possible.

ii. Bent-Leg Sit-Ups

Soldiers will lie on their back with their knees flexed and feet on the ground, fingers interlaced behind their head. They will bend forward at their waist and raise their upper body to vertical. They will then recover to the starting position. They will continue for as many repetitions as possible (a time limit is not specified).

iii. Push-Ups

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their bodies until their chest touches the hand of a judge rested on the ground, and return to the original position. They will continue for as many repetitions as possible (a time limit is not specified).

iv. Knee Bender

Soldiers will stand with their hands on their hips, bend their knees and waist slightly forward, and thrust their arms between their legs until their extended fingers touch the ground. They will then return to the starting position. They will continue for as many repetitions as possible (a time limit is not specified).

v. One-Mile Run

Same as SSPFT

g. Ranger/Special Forces physical fitness qualification test (RSPFT)

i. Inverted Crawl

Same as APFT

ii. Bent-Leg Sit-Ups

Same as APFT

iii. Push-Ups

Same as SSPFT

iv. Run, Dodge, and Jump

Same as APFT

v. Two-Mile Run

Same as APFT

vi. Swim Event

For Ranger trainees, Soldiers will wear clothing and boots, load carriage equipment and their weapons, and swim 15 m. For special forces trainees, Soldiers will swim 50 m with clothing and boots.

E. 1980, 1992, and 1998

a. Army Physical Fitness Test (APFT)

i. Two-minute timed push-ups

Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their bodies until their upper arms are at least parallel to the ground, and return to the original position. They will continue for as many repetitions as possible in the two-minute period.

ii. Two-minute timed sit-ups

Soldiers will lie on their back with their knees flexed and feet on the ground, fingers interlaced behind their head. They will bend forward at their waist and raise their upper body to the vertical position. They will then recover to the starting position. They will continue for as many repetitions as possible in the two-minute period.

iii. Two-mile timed run

Soldiers will run a two-mile course as fast as possible.

b. Ranger Physical Fitness Test (RPFT)

i. Push-Up

Same as APFT

ii. Sit-Up

Same as APFT

iii. Five-Mile Run

Soldiers will run a five-mile course as fast as possible

iv. Chin-Up

Soldiers will grasp a horizontal bar with their palms facing them. They will pull their body directly upward until their chin is over the bar. They will then lower their body until their elbows are completely straight. They will continue for as many repetitions as possible.

F. 2011

a. Army Physical Readiness Test (APRT)

   i. Sixty-Yard Shuttle Run

      Soldiers will run up and down a 25-yard long course as fast as possible. They will change direction every 5, 10, and 15 yards, and pick up and drop off a wooden block at each pivot point. The total distance is 60 yards.

   ii. One-Minute Rower

      Soldiers will lie on their back with their hands over their head and feet six inches off the floor. They will lift up their upper body and pull their knees until their arms are next to their knees. They will then return to the starting position. They will continue for as many repetitions as possible in the one-minute period.

   iii. Standing Long Jump

      Soldiers will squat down and explode forward as far as they can.

   iv. One-Minute Push-up

      Soldiers will lean forward and rest their palms directly underneath their shoulders, while keeping their body straight from head to heels. They will then lower their body until their upper arms are at least parallel to the ground, and return to the original position. They will continue for as many repetitions as possible in the one-minute period.

   v. 1.5-Mile Run

      Soldiers will run a 1.5-mile course as fast as possible.

b. Army Combat Readiness Test (ACRT)

See 3.6.3

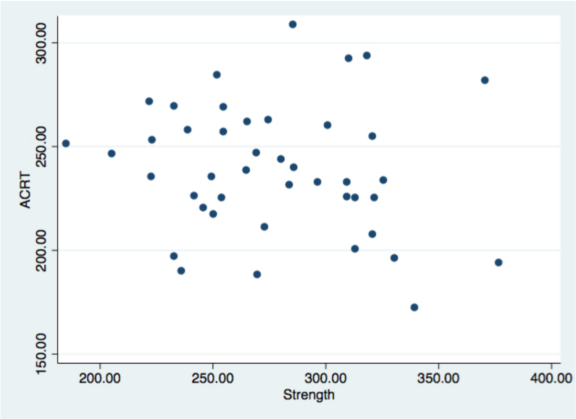
APPENDIX B

SUBJECT DEMOGRAPHIC RECORD SHEET

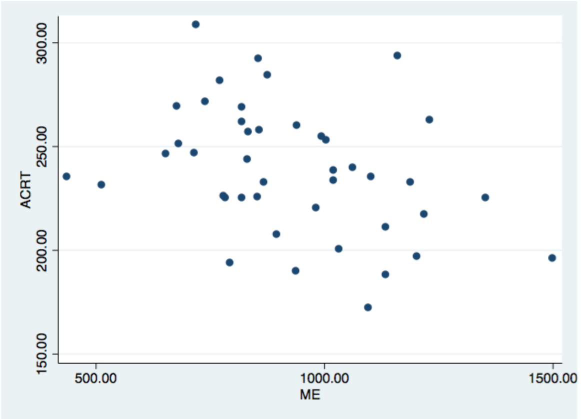
Subject ID		Experience	
Birth Date		Date of Enlistment	
Gender Male		Rank (Pay Grade)	
Height (in)		Unit	
Weight (lb)		MOS	
Dominant Hand		Active and Reserves (Years)	
Dominant Leg		Training	
		Number of Push-ups	
		Number of Sit-ups	
		2-mile Run Time	

APPENDIX C

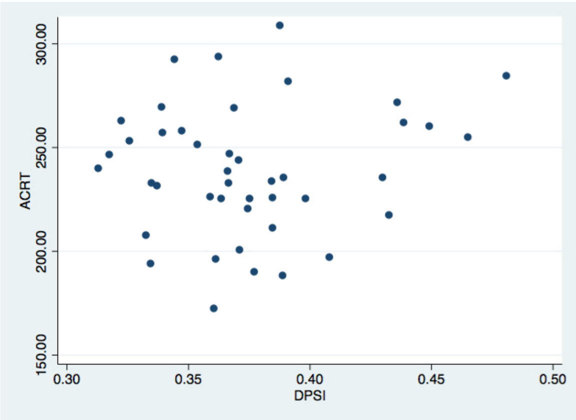
Two-way Scatter Plots for Dependent and Independent Variables



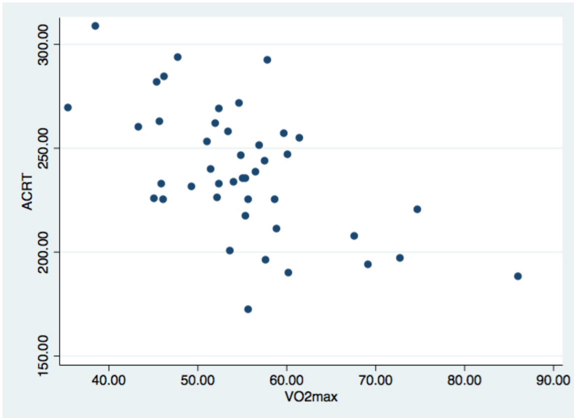
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Average Peak Torque Normalized by Body Mass (Nm/kg)



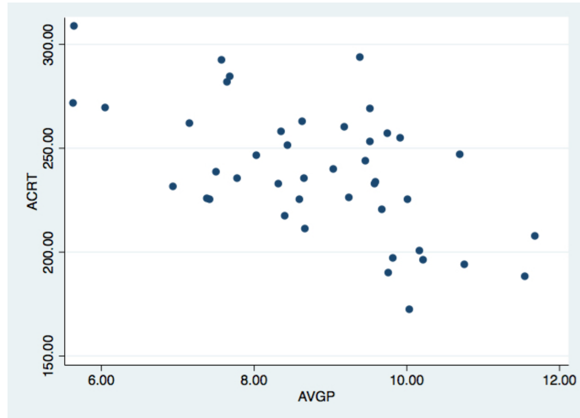
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Total work normalized by body mass (J/kg)



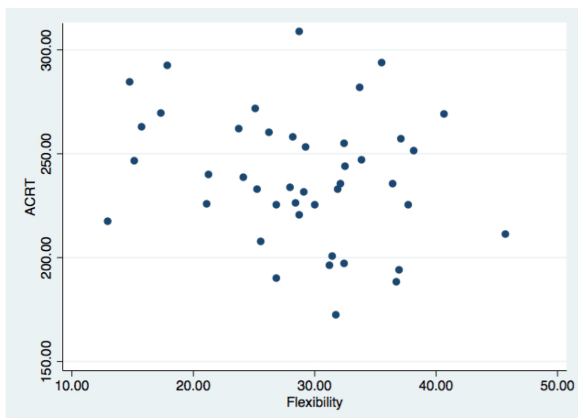
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Dynamic Postural Stability Index



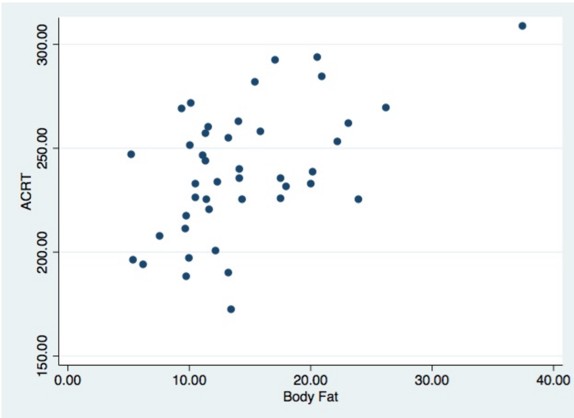
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Maximal Oxygen Uptake Normalized by Body Mass (mL/kg/min)



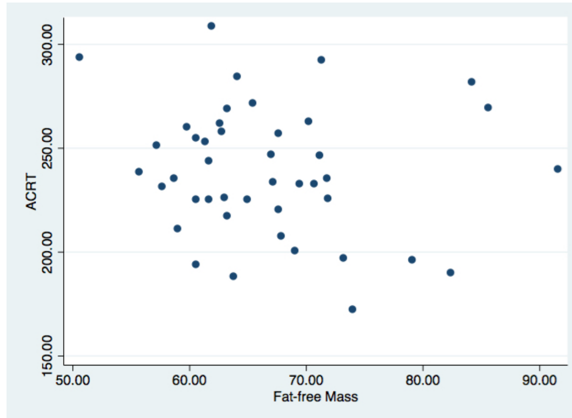
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Average Peak Power Normalized by Body Mass (watts/kg)



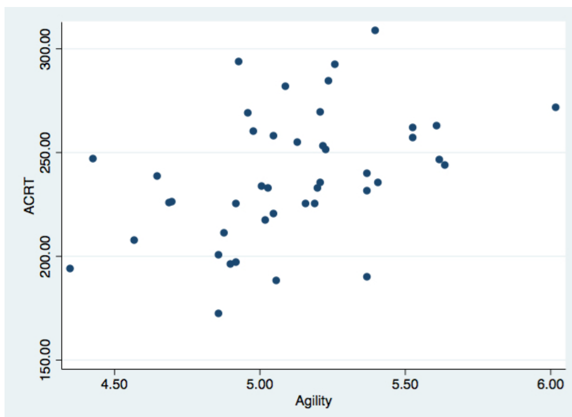
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Sit-and-reach Distance (cm)



Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Percent Body Fat (%)



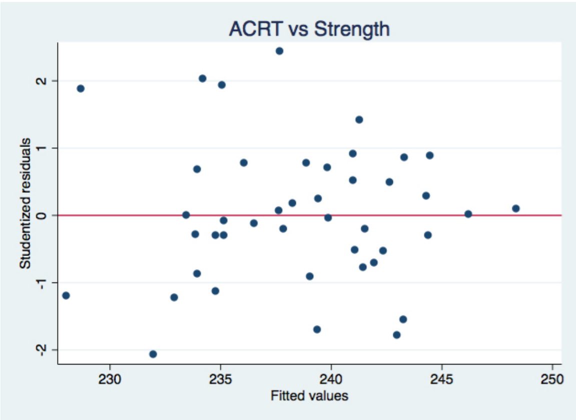
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Mass of Fat-free tissues (kg)



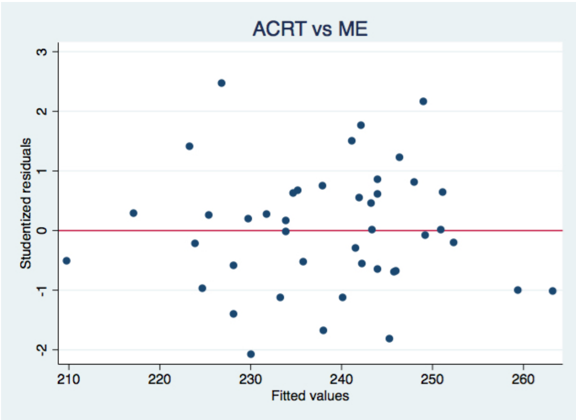
Time to Completion of the Proposed Army Combat Readiness Test (seconds) and Time to Completion of the Pro-agility Test (seconds)

APPENDIX D

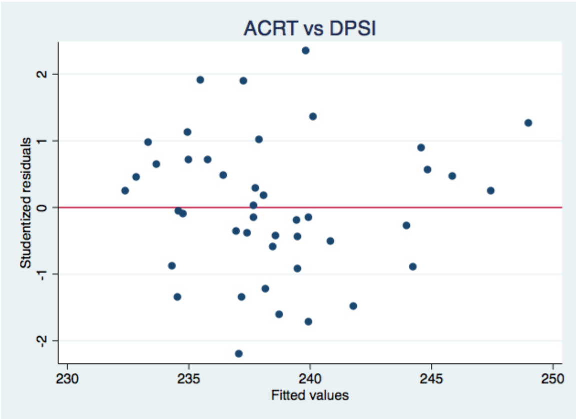
Simple Linear Regression Fitted Values vs. Jackknife Residual Plots for Dependent and Independent Variables



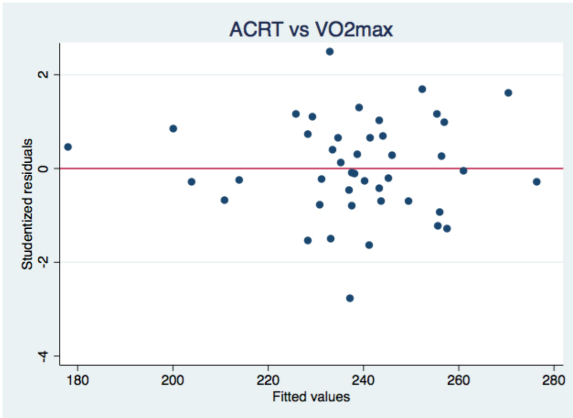
Time to Completion of the Proposed Combat Readiness Test (seconds) and Average Peak Torque Normalized by Body Mass (Nm/kg)



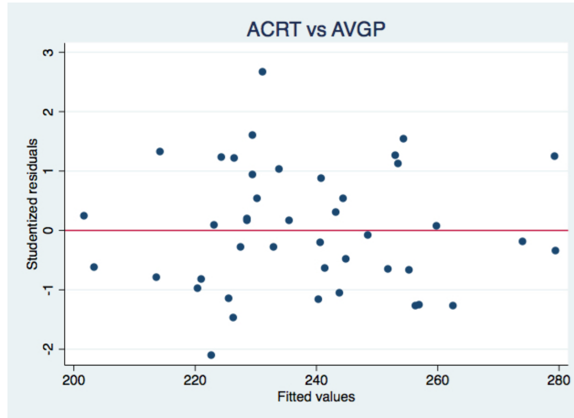
Time to Completion of the Proposed Combat Readiness Test (seconds) and Total work normalized by body mass (J/kg)



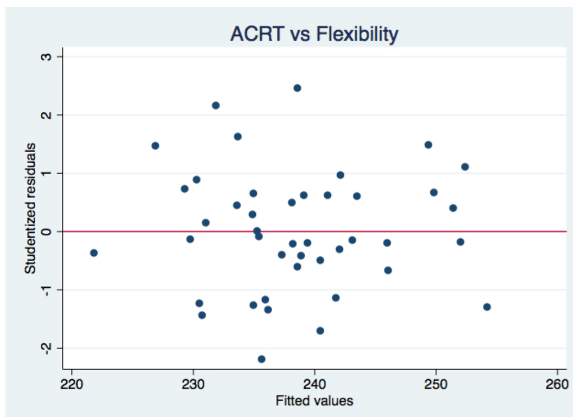
Time to Completion of the Proposed Combat Readiness Test (seconds) and Dynamic Postural Stability Index



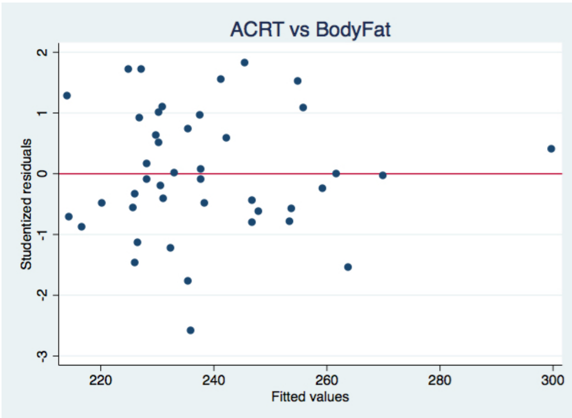
Time to Completion of the Proposed Combat Readiness Test (seconds) and Maximal Oxygen Uptake Normalized by Body Mass (mL/kg/min)

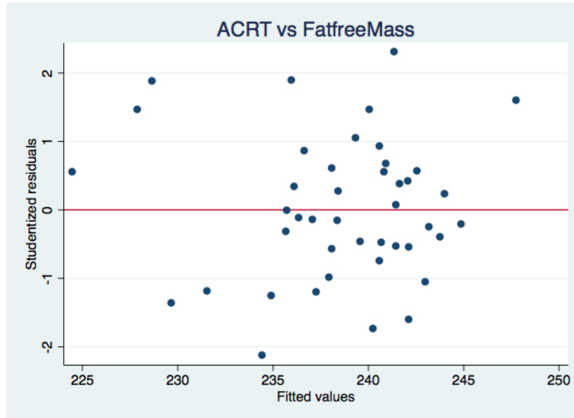


Time to Completion of the Proposed Combat Readiness Test (seconds) and Average Peak Power Normalized by Body Mass (watts/kg)



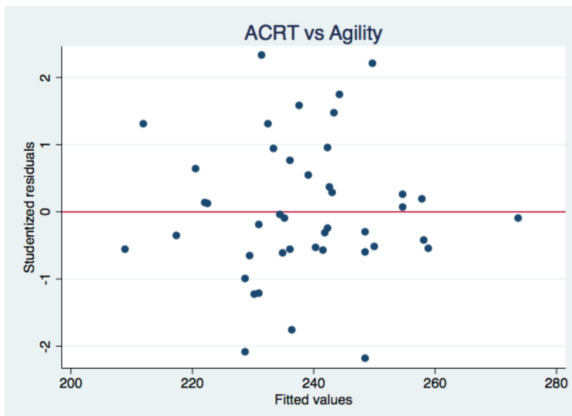
Time to Completion of the Proposed Combat Readiness Test (seconds) and Sit-and-reach Distance (cm)





Time to Completion of the Proposed Combat Readiness Test (seconds) and Percent Body Fat (%)

Time to Completion of the Proposed Combat Readiness Test (seconds) and Mass of Fat-free tissues (kg)



Time to Completion of the Proposed Combat Readiness Test (seconds) and Time to Completion of the Pro-agility Test (seconds)

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